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The Role of the Abdominal Muscles in Pelvic Positioning and Lower Limb Function in Children with Spastic Type Cerebral Palsy

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Declaration

I,, hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is been, or is to be submitted for another degree in this or any other university.

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Executive Summary

Deficient truncal postural control is said to be the main factor in the development of motor disorders, however in cerebral palsy (CP) the role of the trunk especially in lower limb function is not clearly understood. This research project aimed to investigate the role of the abdominal muscles and determine its contribution to the motor dysfunction seen in stance and during gait in children with spastic-type CP (STCP).

This research project consisted of four separate but related studies:

Part One:

As fine-wire electrode electromyography for investigating abdominal muscle activity is not advocated for use in children, the utility of ultrasound (US) imaging was investigated. A descriptive correlational study was employed to determine the validity and reliability of US imaging for measuring the thicknesses of all four abdominal muscles, utilising a sample of six to thirteen year old primary school children with typical development (TD) (n=89) and ambulant children with spastic type diplegic or hemiplegic CP (n=25). Stability of the US measurement in CP was also investigated.

Method Ultrasound images of the four abdominal muscles with children in the supine position were recorded with-in day and between days. Images were captured during rest and during contracted states (during head-up and resisted sling activity). The right side in children with TD and both sides in children with STCP were recorded. The percentage change was calculated between the resting and contracted states in order to investigate patterns of recruitment.

Results Intraclass correlation coefficient (ICC) scores suggest moderate to good intra-tester reliability for the measurement of resting abdominal muscle thickness in children with TD: transversus abdominis (TrA) (.91); obliquus internus (OI) (.90); obliquus externus (OE) (.91) and rectus abdominis (RA) (.94). Inter-tester ICC scores were similar although slightly lower. US imaging could discriminate between active and passive conditions in all four abdominal muscles. ICC scores for thickness measurements recorded during contracted state however showed less stability maybe due to changes in activation patterns between attempts recorded on the same day.

Intra-tester ICC scores (between day scores) were reliable for TrA (.88), OI (.86) and RA (.71). Convergent validity was proven in children with TD in that age and BMI correlated significantly with all thickness measurements. In children with STCP similar ICC scores were recorded for within- [TrA (.95); OI (.85); OE (.89) and RA (.96)] and between day measurements [TrA (.93); OI (.89); OE (.95) and RA (.76)] suggesting that abdominal muscle thickness measures are stable over time. Thickness measurements were also reliable during contracted conditions for all four muscles for within-day repeated attempts in children with STCP.

Conclusion US imaging is a valid and reliable tool for the description of resting abdominal thickness measures. It has shown convergent validity in children with TD and can discriminate between resting and contracted states. In children with STCP US is reliable for investigating change in thickness during sub-maximal contraction however EMG verification of activity in the abdominal muscles is needed to enable appropriate interpretation of levels of activity in these muscles. Responsiveness to change in lower levels of activity is still unknown.

Part Two:

Differences in functional ability as well as differences in structure and anatomical description between children with TD and CP suggest that differences may also occur in the abdominal musculature. As US was shown to be a valid and reliable instrument for investigating most abdominal muscle activity in children, muscle thickness measurements were compared between children with TD and STCP, six to thirteen years of age. Thickness measurements were further explored in children with STCP in the standing position.

Method Measurements using US imaging recorded during rest and during activity in both groups of children were compared using a two-way, mixed effects model ANOVA. Mann Whitney-U tests were used to investigate differences in muscle thickness between male and females. Standard multiple regression analysis was used to identify which variables (age, BMI, gender and diagnosis) were predictive of resting muscle thickness. Images were also captured in the standing position in children with STCP for comparison with measurements recorded in supine.

Results At rest children with CP (n=34) have thicker OI ($p<0.001$), OE ($p<0.15$) and RA ($p<0.02$) muscles than children with TD (n=89) and there was some evidence that the more affected the child, the thicker the muscle. US imaging is reliable for the measurement of resting thickness as well as during leg lift activity for all four abdominal muscles. In standing the TrA ($p<0.042$), OE ($p<0.001$) and RA ($p<0.011$) muscles are significantly thinner than in supine. The relative order of thickness show TrA to be the thinnest muscle followed by the OE; in children with STCP however the OI is significantly thicker than the RA, while the thickest in children with TD is the RA. The RA was significantly recruited during all activities in both groups of children. From the findings of the percentage change in thickness calculated between resting and contracted states, it was found that children with TD recruit the TrA ($p<0.001$), IO ($p<0.031$) and RA ($p<0.001$) significantly more than children with STCP.

Conclusion Preliminary baseline resting thickness measures show that children with STCP have thicker muscles than those with TD. Despite thicker muscles, children with STCP recruit the TrA, IO and RA significantly less than children with TD. Age and body mass index (BMI) are significantly correlated with thickness measurements for all four abdominal muscles in children with TD. These variables are however not predictive of resting thickness in children with STCP. Children with STCP seem to have limited potential for contraction. It is not clear whether the distorted length-tension relationship is mechanical or if it's physiological. Larger studies are needed to establish norms for children with and without pathology.

Part Three:

A descriptive correlational study in a convenience sample of ambulant children with STCP (n=27) aimed to investigate relationships between i) impairments in terms of degree of antero-posterior pelvic tilt and abdominal muscle strength and function in terms of distance walked in one minute; and ii) between resting abdominal muscle thickness measurements and functioning and impairment. The relationship between the iii) change in thickness of the abdominal muscles recorded during sub-maximal activity and functioning and impairment was also investigated.

Method Ultrasound imaging, the 1-Minute Walk Test and 2-D photographic imaging for posture analysis were used to assess abdominal muscle thickness in the supine and standing positions, the distance walked in one minute and posture in standing. The

total number of sit-ups in one minute was also recorded as a measure of abdominal muscle functioning.

Results Pearson's r showed significant correlations between degree of a-p pelvic tilt and abdominal functioning and distance walked. Children with weaker abdominal functioning (ability to execute sit-ups) presented with increased a-p pelvic tilt ($r=-0.54$; $p=0.004$). Similarly children with weaker abdominal functioning covered less distance in one minute ($r=0.58$; $p=0.002$). One way ANOVA suggested no clear relationship(s) between any of the four abdominal muscle thickness measurements and level of functioning (Gross Motor Functioning Classification Scale (GMFCS)). There was some evidence that selected measurements of the OE and RA muscle thickness are related to functional ability in that the % change recorded in the OE muscle in the standing position differed significantly between GMFCS levels II and III, and the resting thickness of the RA muscle recorded in the supine position differed significantly between GMFCS Level I and III. All subsets regression analysis produced similar results suggesting that the percentage change that occurred in the OE muscle during the head-up activity in supine as well as during the contra-lateral leg lift activity in standing are predictive of distance walked in one minute. Measurements recorded for the OE muscle in both the supine and standing positions, as well the percentage change recorded in the OE muscle recorded in standing were predictive of degree of a-p pelvic tilt. The regression analysis also indicated that BMI was significantly predictive of posture in standing - for every 0.88 kg/m^2 increase in BMI children presented with 1° more anterior tilt.

Conclusion Children with stronger abdominal muscles (could execute more sit-ups in one minute) present with less a-p pelvic tilt and are able to walk faster than children with weaker abdominal functioning. No clear relationships exist between thickness measurements and posture and function or the ability to execute sit-ups although it appears that the OE and OE may play an important role, particularly with regard to its ability to generate force reflected by the percentage change between rest and activity. Larger studies and more comprehensive strength profile assessment is recommended.

Part Four:

Based on the findings from the ultrasound imaging and correlational studies as well as current literature a trunk targeted intervention was developed. A single blinded

experimental pre-post crossover study design with random assignment was used to investigate the effect of an abdominal muscle re-education and strengthening intervention in ambulant six to 13 year old children with spastic type diplegic and hemiplegic CP (n=27) on abdominal muscle thickness measurements, recruitment activity as determined by the % change between resting and contracted states, muscle strength, posture, balance and distance walked in one minute.

Method US imaging, the 1-Minute Walk Test, the Paediatric Balance Scale, 2-D photographic posture analysis and no. of sit-ups in one minute were used to assess the effect of a 4-week trunk-targeted strength training exercise program using vibration on gait, balance, posture and muscle thickness during rest and activity.

Results The program resulted in a significant increase in distance walked in one minute ($p<.001$) and upright posture in sitting ($p<.001$) as well as in kneeling ($p<.001$). The intervention also resulted in a significant gain in resting thickness of all four abdominal muscles ($p<.05$). There was no significant change found in recruitment activity of any of the four abdominal muscles during the head up in supine or during the leg lift in standing. An improvement in balance was not detected. While the impact on resting thickness of the OE muscle, posture and the ability to execute sit-ups was maintained at four weeks post intervention, the effect on all other variables was lost.

Conclusion An intervention utilising vibration therapy is effective in improving posture in terms of decreased pelvic tilt and more upright trunk; and gait function in terms of the ability to walk faster. These improvements however were not maintained. Further investigation into exercise dosage parameters is recommended and the possible effect of vibration on hypertonia and spasticity warrant further exploration.

Conclusion and recommendations for future research

In conclusion it can be stated that US is a useful imaging tool and can be used confidently in the abdominal muscles of children with STCP. The abdominal muscles of these children differ from those in children with TD in that they are generally thicker at rest and show a smaller percentage change on recruitment. There are significant relationships between abdominal muscle function (sit-ups), a-p pelvic tilt and gait function but muscle thickness is not predictive of gait ability. However, ability to

contract (as determined by percentage change) of OI is predictive and this muscle showed an increase in thickness after strengthening.

The abdominal muscles can be strengthened in children with STCP and strengthening should be included in treatment and rehabilitation programs aimed at improving function. The vibrating platform seems to have potentiated the impact of strengthening. Safety and long term efficacy of vibration for the re-education and strengthening of the abdominal muscles must still be determined.

While this study has provided some description of the structure and functioning of the abdominal muscles in children with STCP, it is limited. In some ways it is a preliminary study which makes it clear that the abdominal muscles do have an important role to play in function. However the scope of the research was such that the lineages between structure and function were inadequately explored and important questions remain. Are the muscles of children with STCP in a contracted state due to hyperactive reflexes? Are the muscles actually thicker due to increased activity or is it due to morphological changes causing pseudo-hypertrophy? Are the muscles excessively lengthened due to the increased a-p tilt and hence do not demonstrate an equivalent percentage change from resting to contraction? These questions need further exploration.

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List of abbreviations

The following abbreviations were used in the main text:

(ST)CP	(spastic type) Cerebral Palsy
TD	typically developing
NDT	Neuro-developmental therapy
CE	Conductive education
EMG	electromyography
GMFM	Gross Motor Function Measure
GMFCS	Gross Motor Function Classification Scale
MACS	Manual Ability Classification System
TrA	transversus abdominis
OI	obliquus internus
OE	obliquus externus
RA	rectus abdominis
RM	repetition maximum
COM	centre of mass
CNS	central nervous system
PRE	progressive resisted exercise
RCT	randomised controlled trial
PEDI	Paediatric Evaluation of Disability Inventory
2-D GA	two-dimensional gait analysis
3-D GA	three-dimensional gait analysis
EEI	energy expenditure index
PCI	physiological cost index
TUG	timed get-up-and-go test
TIS	trunk impairment scale
BBS	Berg Balance Scale
PBS	Paediatric Balance Scale
LBP	low back pain
US	ultrasound
SRD	smallest real difference
kg	kilograms
m	metre
mm	millimetre

°	degree
BMI	body mass index
SD	standard deviation
ICC	intra-class correlation coefficient
LSD	least significant difference
SEM	standard error of measurement
ANOVA	analysis of variance
MVC	maximal voluntary contraction
MRI	magnetic resonance imaging
ICF	International Classification of Function
PC	personal computer
PSIS	posterior superior iliac spine
ASIS	anterior superior iliac spine
OM	outcome measures
WBV	whole body vibration
Norm.	normality
SW	Shapiro-Wilks test

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Introduction

Cerebral palsy (CP) is a complex neurological condition due to a non-progressive lesion in the developing brain which affects the child's typical development of movement and posture^{1,2}. The impact of the lesion(s) on function is considerable and varying. While some children may demonstrate only slight abnormalities in movement patterns, others may be unable to perform even the most basic functional activities such as sitting independently or eating. Children with typical developmentⁱ (TD) can usually do three to five sit-ups without arm support by the age of five and balance such as in one leg standing is usually only mastered successfully at around five to seven years of age⁵. In contrast, children with CP reach these milestones at a later age and some never master these activities^{6,7}. The complexity and variance in clinical presentation of CP makes decision-making regarding intervention difficult. There are many different schools of therapeutic intervention interpreting the development and significance of the impairments differently and consequently their interventions are also different. Conclusive evidence for the efficacy of many of these interventions remains scarce⁸⁻¹⁸.

Despite ongoing debate regarding the contribution of the primary impairments - muscle weakness vs. spasticity - to the motor dysfunction seen in CP, some researchers maintain that deficient postural control is the main factor in the development of motor disorders¹⁹⁻²¹. Musculoskeletal researchers have increasingly recognized and described the role of the trunk muscles as core stabilizers in lower limb function and have established that there is a relationship between the trunk muscle activity and lower limb

ⁱ While normal refers to the conformity with established standards for humans, typical is defined as having the qualities representative of or that which identifies that group³. When discussing motor development, Emilie Aubert recommends the use of the term 'typical' as opposed to 'normal' as motor ability or behaviour differs across the ages⁴. Therefore when referring to a select group of people - in this instance children between the ages of six and thirteen - the term 'typical' as opposed to 'normal' is preferred.

movement²²⁻²⁴. There is also growing evidence that core stability is essential for maintaining lower back health, as well as preventing ligament injuries in the lower extremities^{25;26}.

The role of the trunk in CP however, especially in lower limb function is often anecdotally described and not clearly understood. Furthermore, the description of the occurrence or presentation of hypertonia in the trunk musculature is inconclusive. Description of the strength and activation patterns of these muscles is also incomplete.

1.1 Background

The prevalence of CP varies globally from about 2,0 to 3,3 per 1000 live births²⁷. It is higher in the lower socio-economic populations and according the Cerebral Palsy Association²⁸, in South Africa it is estimated to be about 2.5 per 1000. At Red Cross Children's Hospital in Cape Town, the CP clinicⁱⁱ reported approximately 350 new cases of CP in 2005. These numbers rose to almost 380 new cases in 2009.

CP is defined as "a group of disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain"¹. The motor disturbance is often accompanied by one or more disorders of sensation-, cognition-, communication-, perception- and/or behaviour problems and/or a seizure disorder. Although CP is not a progressive disorder, secondary complications such as mal-alignments, contractures, leg-length discrepancies, pain and early onset arthritis are also commonly reported in this population and may get progressively worse as the child gets older²⁹⁻³⁵. Loss of function particularly ambulatory function due to high energy expenditure³⁶ has been reported.

There are many approaches to the treatment and management of children with CP ranging from the traditional approach of neuro-developmental therapy (NDT) to interventions that target the primary impairments associated with CP (refer to 2.4). The evidence however for these interventions is somewhat patchy with varied outcome

ⁱⁱ Western Province Cerebral Palsy Association: CP Clinic, Red Cross Children's Hospital

reported among individuals with CP and between studies^{8;11;14;17;37-40}. This inconclusive outcome is not unexpected - architectural and neurophysiological differences between persons with CP and 'normal' development are fairly well described for limb musculature and many interventions target these impairments in the limbs. In the last decade the focus of research in CP has moved towards a more global approach⁴¹ targeting multiple structures⁴²⁻⁴⁵ and with more emphasis on balance and motor control⁴⁶⁻⁴⁸. While the development of postural control is well described in the literature^{20;49;50}, truncal activity during function in the older child - which is usually anecdotally described - is limited and our understanding of the role of the trunk in function remains unclear.

1.2 Impairments and the development of motor control

Children with CP present clinically with a variety of movement disorder patterns which have been classified as spastic, athetoid, ataxic and dystonic type disorders or a combination of these^{1;51}. Exaggerated or hyperactive reflexes, abnormal tone, limited range of movement and a decreased ability to generate force are the primary impairments associated with the brain lesion(s) resulting in CP¹. Stereotyped atypical postural and gait patterns develop in these children although the extent of the impact on function can vary enormously.

Although difficult to quantify reliably⁵²⁻⁵⁴, spasticity in the lower limbs is moderately related to function⁵⁵⁻⁵⁸. There is ongoing research regarding the contribution of muscle weakness to the motor dysfunction seen in CP. Some muscles such as the triceps surae for example have been found to be weaker than expected⁵⁹⁻⁶¹. Several authors have studied the architecture and neural activation of spastic muscles and found several possible explanations for the loss of normal muscle strength. Biomechanical changes such as decreased extensibility⁶², smaller cross-sectional area, shorter fascicle length and decreased fascicle angle⁶³ when compared to age-matched peers may partially explain why these muscles are unable to generate sufficient force. Other contributing factors such as altered motor unit recruitment, firing and modulation⁶⁴ including increased co-activation of the antagonist^{49;60;65;66}, may also contribute to the weakness that children with CP experience.

While in adults the abdominal muscles are well described in terms of structure and function⁶⁷⁻⁷¹, no structural description of the trunk muscles in children was found. Although it could be postulated that these are a smaller version of that seen in adults, structural differences between children and adults have been reported in skeletal limb musculature (refer to 2.4.2) suggesting that these differences could exist in the muscles of the trunk. There is however some description of activity in the trunk muscles of children during selected limb and or trunk movement. Electromyography (EMG) of ventral trunk muscles during sitting balance perturbation has shown abnormal top-down recruitment – neck flexors are activated before the abdominal muscles (rectus abdominis) and there is excessive increased co-activation of the antagonists when compared to normal age-matched peers^{72;73}. These studies suggest that there may be both increased tone and weakness in the ventral trunk muscles. Studies investigating the effect of strength training programs that included exercises that targeted the trunk confirmed that weakness in the abdominal muscles was present in children with CP^{45;74}. Description of the occurrence or presentation of both hypertonia and weakness of the trunk musculature is poor. Lois Blyⁱⁱⁱ postulates that the exaggerated anterior pelvic tilt so often seen in children with CP is due to inactive postural trunk muscles, specifically the abdominal muscles. This tilt in turn makes hip flexion difficult as the iliopsoas muscle is placed in a shortened position which is then not able to generate adequate tension required by the forward swinging leg. The validity of these hypotheses needs to be tested empirically.

Measurement of tone, strength and muscle activity of trunk muscles is challenging. Despite early studies providing evidence for moderate to good reliability for isokinetic dynamometry for the measurement of trunk flexion and extension⁷⁵, researchers in the field of sports medicine^{iv} have more recently questioned its use for measurement of trunk muscle strength. Feasibility and reliability of isokinetic dynamometry for investigating trunk muscle functioning in the paediatric population has not yet been reported. EMG is the preferred method for investigating trunk muscle activity. EMG however, due to the close proximity and overlap of the abdominal musculature requires insertion of wire electrodes to isolate activity in these muscles and is not a technique advocated for use in children. Although surface electrodes can be used, the activity in

ⁱⁱⁱ Training course notes, Cape Town, 1998.

^{iv} Sport Scientist, Sport Science Institute of South Africa, Cape Town

the deeper transversus abdominis muscle, a large core stabilizer cannot be accurately determined⁷⁶. More recently ultrasonic imaging has been used as an alternative, less invasive instrument to describe and evaluate activity in all four abdominal muscles by measuring the thickness of the muscle during contraction⁷⁷⁻⁸³. To the knowledge of the researcher, this technique has not yet been utilised in the CP population.

1.3 Interventions

There are different approaches to the management of children with CP based on the underlying model of the development of motor control. For example the NDT approach emphasizes the importance of neural input to movement and consequently intervention is aimed at attempting to normalise tone, inhibit abnormal reflex activity and facilitate normal movement^{84;85}. In contrast, the motor learning approach and conductive education interprets the impairments as primarily due to a lack of motor control and treatment is aimed at encouraging function to take place^{86, 86;9586}. The biomechanical or orthopaedic approach on the other hand, explains clinical outcome and aims treatment in terms of alignment of the skeletal system and the forces imposed on it by the muscle activity⁸⁷.

There is little consensus as to the most effective intervention for children with CP as individual responses to treatment vary enormously. There is however increasing evidence stating that weak muscles can become stronger in persons with CP, with a low to moderate effect on function^{17;88;89}. Initial studies investigating the effect of strength training programs mainly targeted the extensor muscle groups of the lower limb and included the knee and/or hip extensors and plantar flexors⁹⁰⁻⁹⁴. These strength training programs demonstrated an increase in stride length and a decrease in the degree of crouch. Functional gains as scored by the Gross Motor Function Measure (GMFM) were also reported. Although some training programs did include abdominal muscle exercise(s)^{44;45;74} - as the authors postulated that a stronger trunk would provide a more stable base of support - better lower limb function and decreased energy expenditure was not reported. The clinical relevance of these changes in impairment and level of activity, as well as the long term effects and possible side effects however appears to need further investigation.

The effect of balance training and/or retraining has also been subject to research. A study in a small group of children who unable to sit independently targeted the trunk while sitting on a movable surface⁷⁴. The results of the study showed this intervention to be effective in improving sitting balance. Another study which investigated the effect of reactive standing balance training in children with cerebral palsy⁴⁷ also reported improved balance control. These authors however did not report on the strength or changes in activity which may have occurred in the abdominal or trunk musculature. Other physiotherapy interventions aimed at improving postural control include adaptive seating devices, lower limb orthoses and neuro-developmental therapy. A systematic review of physiotherapy enhancing postural control in children with cerebral palsy however indicates that evidence for efficacy of these interventions is inadequate⁹⁵.

To the knowledge of the researcher, no studies have been undertaken which target the postural muscles specifically in terms of strengthening the muscles, increasing the endurance of these muscles and educating their postural alignment functions (e.g. maintaining normal pelvic alignment).

1.4 Statement of the problem

The complexity of the development of motor control in CP and the lack of conclusive evidence for intervention make decision-making regarding management and treatment of these children a challenge for the multi-disciplinary team. There is a lack of empirical description regarding the nature of the impairments with regard to trunk and lower limb control. Several questions arise from the literature: How can the function of abdominal muscles in children be described and quantified in a non-invasive manner? How do the abdominal muscles in children with typical development compare with children with CP in terms of structure? What is the role of the abdominal muscles in positioning of the pelvis and how does this effect lower limb function? Is there a relationship between poor postural control, activity in the abdominal muscles and function? How are the postural muscles activated, with regard to range of action and sequencing of activation in stance and during gait? What is the relative strength of the postural muscles and does weakness of the trunk impact on the gait pattern?

It was the researcher's contention that ultrasound imaging of the trunk musculature at rest and during activity in supine and in standing as well as analysis of standing

posture and gait would contribute to a better understanding of the role of the trunk in lower limb function and would allow for the development of more appropriate and effective intervention techniques. It was postulated that an intervention targeted at improving the strength and activation patterns of the postural muscles would result in improved function.

As spastic hemiplegia and diplegia are the most common types of CP seen²⁷, it was thought appropriate to describe the trunk and lower limb muscular impairments with regard to strength and recruitment activity in children with these conditions, to help researchers further their understanding of the strategies used by these children for forward propulsion, locomotion and function. The intention was to use this information to assist in development of best practice protocols for strength training interventions targeting specific muscle groups found to be deficient, for the treatment and also ongoing (re)habilitation of this population.

1.5 Aims and objectives of the study

In light of the above, the research project had four primary aims. Firstly the researcher intended to establish if US imaging was a valid and reliable method of describing abdominal action in children. Secondly she wished to compare the US images of the two groups of children to determine if there were any differences between the two. The third aim was to investigate the relationship between structure and function of the abdominal muscles, as determined by US imaging and relate these to the motor dysfunction seen in stance and during gait in children with spastic-type cerebral palsy (STCP). Finally, the researcher aimed to develop and test a best practice trunk targeting intervention strategy for more efficient lower limb function.

Four separate but related studies were undertaken to meet these objectives. The specific objectives for each of these studies were as follows:

1.5.1 Establishing the reliability and responsiveness of US measurement of abdominal muscles in children with TD and children with CP

In a sample of primary school children with TD and ambulant children (with or without walking aids) with spastic-type cerebral palsy (STCP), the specific objectives were to:

- determine the validity and reliability of ultrasound imaging in children
- establish and compare baseline values for resting abdominal muscle thickness measurements in children with TD and in children with STCP

1.5.2 Comparison of abdominal muscle activation in children with TD and children with STCP

In a sample of primary school children with TD and ambulant children (with or without walking aids) with STCP, the specific objectives were to:

- describe and compare abdominal muscle activity in supine in children with TD and STCP
- describe abdominal muscle activity in standing in children with STCP

1.5.3 Establishing the relationship between resting and active abdominal muscle thickness and function in children with STCP

In a sample of ambulant children (with or without walking aids) with STCP, the specific objectives of the correlational study were to determine whether:

- there was a relationship between muscle thickness measurements and strength of the abdominal muscles
- there was a relationship between muscle thickness measurements or strength and the position of the pelvis regarding anterior-posterior tilt
- there was a relationship between muscle thickness measurements or strength and self-selected fast walking
- the position of the pelvis in terms of anterior and posterior pelvic tilt was a determinant of walking speed

1.5.4 Intervention development and testing

The objective of this study was to develop an effective intervention strategy based on the findings from the ultrasound imaging and correlational studies as well as current

literature. An experimental study then investigated the effects of a trunk targeting intervention in ambulant children with spastic-type diplegic or hemiplegic cerebral palsy, on:

- resting abdominal muscle thickness
- transversus abdominis (TrA), obliquus internus (OI) and externus (OE) and rectus abdominis (RA) recruitment activity
- posture
- balance
- distance walked in one minute
- number of sit-ups in one minute

1.6 Significance of the study

Cerebral palsy is a disabling lifelong condition which occurs in approximately 15 000 children in South Africa. The impact on function is severe and even those affected who do manage to ambulate often do so at the cost of considerable energy expenditure. Independent locomotion is often lost as the child matures. A better understanding of the role of the trunk in lower limb function will contribute to more appropriate and effective decision-making regarding management and treatment of these children. An intervention based on empirical evidence of muscle imbalances and weakness might be found to be effective in allowing more children to ambulate, improving the gait of those who are walking and to extend the period of time that the child is able to walk independently.

Overview of the Literature

2.1 Structure of Review

Searches on the PubMed, CINAHL, Cochrane, PEDro, PsychInfo and Science Direct databases were undertaken with the following main key words: abdominal muscle strength and activity, trunk control, postural control and core stability, cerebral palsy, motor development, motor function and gait. These produced much literature pertaining to the role of the trunk musculature into core stability predominantly in adults in both the orthopaedic and sports sectors. Extensive literature pertaining to cerebral palsy (CP) in both paediatric and adult populations including epidemiological, clinical descriptive and intervention research was also found and reviewed.

The first section of this literature review deals with current knowledge and theories related to the role of trunk musculature - particularly the abdominal muscles- core stability and the role thereof in lower limb function. The next section deals with the extent of the problem and attempts to explain why, despite the improvement in medical care, the incidence of CP does not continue to decrease. The next sections present literature pertaining to the impairments and functional limitations present in those with CP. The different approaches to treatment and intervention strategies with the literature supporting the theoretical foundations of these different methods are discussed with particular emphasis on interventions targeting the trunk and lower limbs to improve functioning. The use of standardized outcome measure to monitor, and detect change in both the impairments and functional limitations of children with CP, is also discussed.

2.2 Core stability, strength and the role of the abdominal muscles

This section of the review focuses on the current knowledge and issues pertaining to the concept of 'core stability'. Definitions and interpretations of the structures and mechanisms involved in postural control differ between the rehabilitation and sports sectors. Similarly there is debate around the relevance of core muscle strength and its contribution to motor performance. A brief description of the anatomy and functional

anatomy of the core stabilisers is also given. Where abdominal muscle activity in children (with or without pathology) has been described in the literature, this is also discussed.

2.2.1 Definitions

Definitions pertaining to core stability and core strength differ between the rehabilitation and sport performance sectors in that although the process can be defined, what is anatomically included in these definitions vary. The focus in rehabilitation is on control of spinal loading - i.e. enabling the broader population to perform activities of daily living; while the focus in the sport performance arena is to maintain stability during highly dynamic and highly loaded movements⁹⁶. For example, Panjabi (1992) suggests that core stability is an integration of the passive spinal column, active spinal muscles and neural control. When combined the intervertebral range of movement is maintained and allows for activities to be carried out⁹⁷. Kibler et al. (2006) on the other hand summarises core stability as “the ability to control the position and motion of the trunk over the pelvis to allow optimal production, transfer and control of force and motion to the terminal segment in integrated athletic activities”(p189)⁹⁸.

There is a fundamental difference between core stability and strength. Stability refers to the ability to stabilise the spine whereas core strength refers to the ability of these muscles to generate *sufficient* force to counteract external forces or perturbations²³. This differs from the definition of muscle strength used in the sports sector which states that muscle strength refers to *maximal* force that can be generated at a specific velocity within those muscles⁹⁹. As such interventions targeting the core stabilisers differ between sectors. In rehabilitation the emphasis is on correct functioning – automatic recruitment and appropriate low level tonic activity⁷⁰; while in sports performance exercise involves highly dynamic movement with added resistance⁹⁶.

2.2.2 Functional anatomy of the ‘core’

The core is often described as a cylinder with the abdominal muscles in front, the paraspinal and deep gluteal muscle fibres at the back, the diaphragm forming the roof and the pelvic floor and hip-girdle muscles, the base¹⁰⁰. Functional stability is dependent on integrated functioning of two systems, namely the local stabilisers and the global stabilisers¹⁰⁰. The local stabilisers – transversus abdominis (TrA), multifidus,

interspersalis and interspinalis (lumbar part), obliquus internus (OI) and quadratus lumborum (medial fibres) - offer intersegmental vertebral stability and spinal orientation; while the global stabilisers -obliquus externus (OE), rectus abdominis (RA), quadratus lumborum (lateral fibres) and longissimus and intercostalis (thoracic part) - provide general trunk stability, generate torque and provide control over some motions¹⁰¹. The stabilising muscles are mainly responsible for maintaining posture, while the global and mover muscles contribute to rapid movement, force and power¹⁰¹. In the sport sector muscles of the shoulder girdle, diaphragm and pelvis are recommended to be included as part of the core musculature^{102;103}. As the abdominal muscles are attached to the lower ribs, vertebral column and pelvis, control of the diaphragm is essential to stabilise the thoracic wall to allow more efficient activity in the abdominal muscles⁶⁹. Similarly an important role of the gluteal muscles and pelvic floor is to stabilise the pelvis⁶⁹.

Although the four abdominal muscles collectively provide stability and allow or produce movement, there are differences in anatomical structure and morphology and therefore different levels of activity may occur in each muscle¹⁰⁴. The TrA, the deepest of the abdominal wall arises from the inguinal ligament and inner lip of the iliac crests inferiorly, the thoracolumbar fascia posteriorly and the inner surface of the costal cartilages of the lower six ribs superiorly where it inter-digitates with the attachment of the diaphragm; has upper fascicles that are horizontal and middle and lower fascicles that are inferomedial¹⁰⁴.

The fibres of the OI muscle - with its attachment to the outer border of the lower eight ribs and their costal cartilages – sweep downwards and medially and attach to the outer lip of the iliac crest. The upper fibres form part of the rectus sheath. The OI lies deep to the OE and where the OI arises from the inguinal ligament anteriorly, and iliac crests and thoracolumbar fascia posteriorly the fibres fan outwards with the most posterior fibres running almost vertically to attach to the inferior border of the lower four ribs. The more anterior and lower fibres pass upwards and medially. It has been demonstrated that activity of the upper and lower fibres of the OI vary during posterior pelvic tilt¹⁰⁵. Insert OE anatomy

The fibres of the RA muscle run vertically upward and attach to the xyphoid process and costal cartilages of the fifth, sixth and seventh ribs⁶⁹. All the abdominal muscles are connected anteriorly to each other via the rectus sheath. Bilateral activity in RA, OI and OE produces trunk flexion and if the ribs are fixed can alter the position of the pelvic tilt

and decrease the lumbar lordosis. These muscles are also involved in rotation and lateral flexion of the trunk. Due to its attachment on the iliac crests, the TrA functions as a 'sheet muscle' (p475) and provides stability to the trunk and pelvis by increasing the pressure in the abdominal cavity⁶⁹.

Symmetrical activity is usually seen in the local stabilisers even during asymmetrical load, while the global stabilisers show asymmetrical patterns of activation during the same tasks^{106;107}. The TrA has a preparatory stabilising effect and contributes to pelvic and lumbar stability making allowing movement in the limbs to occur^{23;76} and is active regardless of body movement direction, unlike the other abdominal muscles¹⁰⁸.

The anatomy of the lumbar spine, thoracolumbar fascia and osseous and ligamentous structures, also contribute to lower spinal stability together with the surrounding musculature. If there is over activity in the global mobiliser muscles or if there is inactivity in the local system, movement in the trunk becomes restricted and compensatory (balance recovery) and movement patterns are less efficient¹⁰⁰. Kim et al. (2006) concluded that an imbalance in trunk muscle strength can significantly influence the lumbar lordosis¹⁰⁹. Similarly it could be hypothesised that hypermobility in the lumbar spine resulting in an increased lordotic curve can over lengthen the abdominal muscles inhibiting their ability to contract⁶⁸ and contribute to spinal stability⁷⁰.

There is some controversy regarding which muscles to observe when assessing functioning of the core stabilisers. Comerford and Mottram (2001) emphasis RA activity as this muscle has a high recruitment threshold and braces the spine during heavy lifting activities, while the OE and OI muscles contribute more to posture and stability¹⁰⁰. Hodges, Richardson and colleagues however have emphasised the importance of the TrA and OI muscles in lumbar spine stability^{23;76;81;108;110}. The role of the psoas muscle is also somewhat controversial regarding its contribution to stability of the lower spine and pelvis¹¹¹. The author states that differences in anatomical description of the attachments of the psoas muscle make interpretation of involvement in stabilising function difficult.

2.2.3 Trunk muscle activity and functional performance

Research suggests that, in adults, relationships exist between the trunk muscle activity, force production and function¹¹²⁻¹¹⁵. Although activity in selected trunk muscles has been shown to correlate with strength in those muscles, the relationships differ somewhat in men and women. While in men this activity : force production relationship is non-linear, a more linear relationship was found in women¹¹². The same study showed that females demonstrated greater activity in the trunk musculature compared to men and also presented with higher levels of co-contraction of trunk muscles when attempting to maintain straight posture¹¹². Nesser and colleagues (2008) found strong to moderate correlation between core strength - which included trunk flexion, back extension and right and left bridging - and selected power and field performance tests such as the 20 and 40 yard sprint, shuttle sprint, one-repetition max (1RM) squat and 1RM bench press in divisional football players¹¹⁴.

Despite an increase in strengthening exercises targeting the core, the impact in sport performance is yet to be demonstrated⁹⁶. In rehabilitation however, significant improvement in pain-free movement^{116;117} and a decrease in recurrent lower limb injury¹¹⁵ have been reported following re-education and strengthening of the core musculature.

2.2.3.1 Trunk kinematics and muscle activity during balance

Most studies investigating balance control and recovery strategies in both adults and children have limited their investigation to recruitment patterns of superficial lower limbs and trunk musculature and investigation into abdominal muscle activity is limited to the RA muscle only^{48;49;118;119}. In adults, EMG measurements of trunk muscle activity have also been recorded during unstable squat movements¹¹³ and while standing on a multi-directional support surface/balance board¹⁰⁷. These studies (in adults) confirm involvement of all four abdominal muscles and demonstrated that pre-activation occurs in all four muscles but that this and the level of activation is task-related. While TrA is symmetrically active during all these balance movements and perturbations, the level of activity in RA, OI and OE is direction dependent^{107;113}. Another two studies - one that investigated abdominal muscle activity during various abdominal targeted exercises, which included the 'plank' and wobble board balance exercises¹²⁰; and another which investigated back and abdominal muscles activity during various stabilisation

exercises¹⁰⁶ - also confirm that recruitment patterns and levels of activity of RA, OI and OE muscles are task-related.

While studies have been published investigating postural control mechanisms in children with CP^{72;73;119} these studies did not report on activity in all the abdominal muscles; and only included RA muscle activity. Results however suggest that there is abnormal top-down recruitment^{21;73}, abnormal firing and excessive co-contraction between the dorsal and ventral muscles as well as poor modulation of contraction^{50;66;73}. Although not recorded in any of these studies abnormal recruitment and firing could be expected in all four abdominal muscles in children (and adults) with motor dysfunction.

2.2.3.2 Trunk kinematics and muscle activity during gait

There is a paucity of literature regarding description of detailed truncal kinematics in both adults and in children. While there is some description regarding global truncal movement during gait in normal adults, there is little published data investigating relationships between trunk kinematics and lower limb distance parameters in persons with pathology and similarly in children (refer to 2.6.1.1). One of the problems associated with measurement of truncal kinematics is the complexity of the biomechanics of the spine and the many vertebral joints which collectively contribute to the global movement of the trunk. Normative data produced by Troke et al. (2005) describes lumbar flexion-extension, side flexion and rotation of the trunk during the gait cycle¹²¹. One study investigating gait strategies in children with CP did infer abnormal truncal movement from changes in position of the centre of mass (COM)¹²². The description however was limited to vertical displacement only. Observational analysis shows that typically children with spastic type CP use excessive side flexion to compensate for decreased lateral weight transfer⁸⁷.

A study by Anders et al. (2007) describes RA, OI and OE activation patterns during walking at different speeds in adults and confirms involvement of the abdominal muscles in gait function and both phasic and tonic activity is reported¹²³. The authors also concluded that although there are differences in individual muscle activation strategies for walking at different speeds, the increasing cumulative effect correlates with increasing walking speed. Whether these relationships exist in children however remains to be established.

While there is evidence that the abdominal muscles are related to lower limb function and there is some evidence that suggest that strengthening the abdominal muscles can impact balance and gait function, in order to plan optimal intervention there is a need for better description of individual abdominal muscle activity and optimal patterns of recruitment. This is particularly so for children and persons with motor dysfunction.

2.3 Magnitude of the problem in cerebral palsy

2.3.1 Definition and implications

Cerebral palsy (CP) was first described by Little in 1862 and initially referred to as 'cerebral paresis'¹²⁴. Since then the definition has undergone continuous revision to include and adapt to the most recent evidence in the neurodevelopmental field. CP is currently described as an umbrella term which describes a "group of disorders of the development of movement and posture, attributed to non-progressive disturbances that occurred in the developing foetal or infant brain"¹. Clinically children with CP present with postural problems and a range of ambulation and upper limb activity limitations. Several co-morbidities may accompany the disorder. Seizure disorders occurs in about 20-40% of children with CP, up to 80% have some impairment in speech, half have gastro-intestinal or feeding problems²⁷, a quarter present with stunted growth and many are either over- or underweight¹²⁵ and have lower physical fitness than their normal peers²⁷. Although the impact of these impairments varies, the child's ability to function normally may be affected⁵ which has implications for independent and productive social life.

2.3.2 Aetiology and epidemiology

Most studies investigating the causes of CP suggest that there are many pathways and that many of the causes may be multi-factorial. A prevalence survey in Sweden indicated that in term children approximately 50% had preterm aetiology, 36% peri- or postnatal and about 12% could not be classified. In preterm children these figures were 12%, 61% and 27% respectively¹²⁶. An updated more recent 2010 survey revealed that preterm aetiology has shown a decrease and dropped to 36%, while 42% of cases occur in the peri/neonatal period¹²⁷. Twenty one percent of cases remained

unclassified. The most common prenatal risk factor for CP is inter-uterine infections. Low birth weight infants for example with a history of sepsis, quadruples the risk of CP¹²⁸. Peri natal risk factors include convulsions, birth asphyxia, jaundice, ante partum haemorrhage and neonatal infection. Multiple gestation is another risk factor for CP with a prevalence of about 2.3 per 1000 in singletons, 12.6 in twins and 44.8 in triplets¹²⁹. Cerebral infections such as meningitis, cerebral malaria and septicaemia, and convulsions are the most common postnatal aetiologies for both developing and First World countries¹³⁰. The prevalence however of postnatal or post-neonatal acquired CP is reported to be considerably higher in African countries and in poorer socio-economic populations with head-injury, pertussis, gastro-enteritis and dehydration most commonly reported^{131;132}.

A review of the literature from 1965 – 2004, by Odding et al. (2005) indicates that the prevalence of CP in European countries in the last 40 years has risen from about 1.5 per 1000 live births in the 1960's to about 2.5 in the 1990's. Despite improved anti-natal care and neonatal medicine, the survival of extremely low birth weight infants may account for the rise in incidence. Newborns weighing less than 2,5kg contribute to half of all the cases of CP and just over half of the most severe cases. There has also been an increase in the presence of low severity dysfunction including learning disabilities and attention and hyperactivity disorder (ADHD)¹³³. It has been suggested that these children also have underlying motor dysfunction¹³⁴.

The reported prevalence of CP in other parts of the world is very similar. In the both the United States¹³⁵, Northern Ireland¹³⁶, Australia¹³⁷ and Sweden¹²⁷ for example, 2.0 to 2.5 per 1000 live births have been reported. In British Columbia the aggregate prevalence was slightly higher and estimated at 2.68 per 1000 live births¹³⁸. In China the prevalence figures are a little lower with 1.6 per 1000 children¹³⁹. Similarly in India prevalence figures are reported to be lower than in Western countries¹⁴⁰. Prevalence figures for other African countries are scarce and/or out dated. The current figure in South Africa is unknown however it is estimated to be about 2.0 to 2.5 per 1000 live births²⁸ similar to figures reported in the US and Europe. The reported incidence of CP in the lower socio-economic populations seems to be higher. Prevalence figures of 3.33 per 1000 in United Kingdom's most deprived areas¹⁴¹ and a house to house survey in a Turkish county estimated data at 5.6 per 1000 for children below the age of 6 yrs¹⁴² have been reported. A prevalence study by Molteno and Arens (1996) of seven to nine year old children with cerebral palsy living in Cape Town, reported figures of

2.21 per 1000 live births for white populations. Although this study reported separate prevalence figures for three self-identified ethnic groups i.e. 2.86 per 1000 for the coloured population and 4.65 for the African population, these figures more likely reflect socio-economic rather than any genetic cause.

The distribution of the sub-types of CP has also changed in more recent years. The majority of children presenting with CP are still of the spastic type (72-91%), while the incidence of diplegia has decreased (13-25%) that for hemiplegia has increased (21-40%). Approximately six to 17% present with dyskinesia and +/- 5% present with ataxia^{27;143-148}.

2.4 Impairments of function

2.4.1 Classification

A better understanding of the development of motor control has improved early detection of children at risk for developing CP^{149;150}. Despite this early accurate diagnosis remains difficult. There are several approaches to classifying persons with CP and usually the level or distributional pattern of motor involvement for example hemiplegia, diplegia, triplegia or quadriplegia as well as the predominant movement disorder for example spastic, athetoid, ataxic or dystonic type, are typically described⁴¹. This however does not describe the nature of the problems nor the severity and therefore does not predict functional outcome or prognosis. At an international workshop on Definition and Classification of Cerebral Palsy in Maryland, USA in 2004 four dimensions were proposed for inclusion in order to more accurately classify persons with CP¹. A revised version was published in 2007².

Motor abnormalities

The predominant as well as any associated movement disorders, as described above - spastic, athetoid / dyskinetic, ataxic and dystonic - should be noted as well as the functional motor ability. Ambulatory motor ability can be classified using the Gross Motor Function Classification System (GMFCS)^{5;151}. It is a five-level age-categorized system representing differences in motor function. A similar system, the Manual Ability

Classification System (MACS) is under development for upper limb function. Although bulbar and oromotor problems can also impact on speech, communication and feeding, there are no scales as yet to measure this, but should be reported.

Associated impairments

Apart from the movement disorder a seizure disorder, hearing and visual problems, communication, cognitive and attention deficits and or emotional and behavioural disturbances may also accompany and influence the outcome of the motor impairment and should be classified as either present or absent.

Anatomic and radiological findings

The level or distributional pattern of involvement must be described not just for the upper and lower extremities, but for the trunk and oropharynx as well especially with regards to unilateral or bilateral involvement. Using the terms diplegia and quadriplegia etc. has been contested however it has been proposed that the term is rather expanded¹⁵². Especially with the mixed types of CP subtle signs of involvement in supposedly unaffected limbs may be observed which may be directly related to the lesion or occur secondary due to the lack of development through lack of motor experience⁴¹. Although radiological findings correlate poorly with clinical presentation it is recommended that where possible they should be recorded.

Causation and timing

Adverse pre-, peri- or postnatal events should be recorded although these events alone are not necessarily causative of CP in the affected individual^{27;135;137;153}.

2.4.2 Impairments

The primary physical impairments due to the cerebral lesion that contribute to the clinical presentation of these children include spasticity, hyperactive reflexes, hypo-extensibility and a decreased ability to generate force. Three-dimensional gait analysis, electromyography (EMG) and the use of standardized functional outcome measures have made it possible to more accurately describe the clinical presentation of children with CP.

2.4.2.1 Muscle weakness

Clinically children with CP have shown muscle weakness to co-exist with spasticity. There is however variable description in the literature regarding the contribution of muscle weakness to the motor dysfunction seen in CP^{64;90;154}. Studies by Wiley and Damiano (1998) and Ross and Engsberg (2002) found that no relationship exists between spasticity and strength and the authors concluded that a spastic muscle is not a strong muscle and vice versa. They also found that weakness was more pronounced distally in both hemi- and diplegics with the strength around the ankles being weaker than the muscles around the knee. Imbalance of muscle strength across joints has been reported. For example the hip flexors and ankle plantar flexors tend to be stronger than their antagonists^{61;154}. Strength profiles for the trunk in children with CP have rarely been reported in the literature however functional assessment in studies of interventions targeting the trunk, suggests that these muscles may also be weak^{95;155}. In these studies - in the absence of a more objective measure - counting the number of sit-ups executed was used to determine muscle strength (refer to 2.5.6).

Mockford et al. (2010) conclude in their extensive review of the literature that altered and impaired neural drive, and histological and architectural changes in muscle structure are reasons for the weakness seen in muscles of persons with CP¹⁵⁶. The muscles in children with spastic type CP present with smaller cross sectional area, shorter fascicle length and increased fascicle angle^{63;157-159}. Spastic muscle fibres show shorter resting sarcomere length. It has been suggested that extensive remodelling of both intra- and extracellular structural components such as titin and collagen occurs making the muscle less extensible¹⁶⁰. Shortened whole muscle length and increased resistance to passive movement alters the length tension curve which also contributes to the weakness seen¹⁵⁶. During contraction, actin filaments slide across myosin filaments to form cross-bridges⁶⁸ but if a muscle is already in a shortened position no further sliding is possible. Alternatively when the muscle is over-lengthened, as can occur due to prolonged mechanical stretch, the actin has difficulty in sliding across and is unable to activate an efficient contraction⁶⁸.

A muscle's contractile properties are also influenced by the characteristics of the particular innervating motor neuron and are prone to change if the electro-physical properties of the neural system change¹⁶¹. EMG studies in children have shown that during maximal contraction activation is considerably less in children with CP compared to age-matched controls in that children with CP are unable to recruit higher

threshold motor units or able to drive lower threshold motor units to higher firing rates¹⁶². At submaximal level however, the authors demonstrated that motor-unit recruitment and firing rates were not different between children with CP and TD. Short-term synchronization in children with CP was however reduced when compared to children with TD¹⁶². While these results pertain to the medial gastrocnemius and tibialis anterior muscles they most likely apply to all limb muscles affected by the brain lesion.

Similar abnormal characteristics are also displayed in the postural muscles. During perturbations in sitting children with CP exhibit muscular activity counteracting the forces that disturbed equilibrium, but have difficulty in efficiently adapting the adjustment⁴⁹. A top-down recruitment of postural muscles, an excessive degree of antagonistic co-activation and an incomplete adaptation to task specific constraints suggests greater dependence on recruitment rather than firing rate modulation to control the force. Although the authors postulate that the co-contraction is task-related rather than an indication of abnormal tone, it does reduce the efficiency of agonist contraction and leads to fatigue and weakness^{49;73}. Kwakkel's (2000) 'subtraction paralysis theory' hypothesizes that the co-contraction between the agonist and antagonist is responsible for the reduced net force production in the agonist⁴¹. In relation to the trunk, this theory suggests that the excessive co-contraction in the dorsal and ventral muscles may be responsible for the weakness seen in the abdominal muscles.

Development and change in fibre type may also contribute to muscle weakness seen in CP¹⁵⁶. While the proportions of type I (slow) and type II (fast) vary according to the muscles main function – stabiliser vs. mover function - there is some controversy in the literature regarding dominance of fibre type in spastic muscles. It has been reported that damage to the central nervous system with the associated loss of supraspinal impulse inhibition¹⁶³, level of activity and perhaps the ability to weight bear¹⁵⁷ may interfere with the maturation of the myosin and hinder the reacquisition of slow-twitch properties in certain muscles during typical growth, while the initial development of slow into fast-twitch fibre type is not affected. Biopsies however suggest that the musculature of ambulant children with CP exhibit a dominance of type I fibres and reduced type II fibres¹⁶⁴ and as this fibre type dominance reflects that of a stabilising muscle, it is not surprising that muscles which are expected to exhibit phasic qualities (e.g. the gastrocnemius muscle) now display tonic muscle characteristics and are unable to generate rapid high torque contractions.

Although CP is not a progressive disorder, over time secondary complications occur due to weakness and tone imbalance. A decrease in mobility and an increase in sedentary lifestyle result in further muscle weakness and atrophy as well as soft tissue contracture^{29-31;33;35;62;165}. The abnormal forces imposed by the muscles on the skeletal system result in biomechanical mal-alignment such as increased lumbar lordosis, anterior tilted pelvis, femoral neck ante-version and femoral and tibial torsion. The abnormal alignment alters the line of pull of the muscle resulting in weakness. For example coxa valga at the hip effectively shortens the abductors decreasing trunk and pelvic stability⁸⁷ which decreases the ability of the lower limb to propel the body forward. Similarly, although currently it is unknown which is cause and which is effect, the anterior tilt of the pelvis lengthens the abdominal muscles inhibiting the ability for these muscles to contract and sufficiently stabilize both the trunk and the pelvis⁸⁴.

Pain and early degenerative changes due to abnormal compression forces in weight-bearing joints exacerbate the secondary complications^{29;165;166}. Weakness in this population may also be increased by some of the procedures that children undergo to address certain physical impairments, for example selective dorsal rhizotomy reveals weakness by reducing the anti-gravity support that may have been provided by the spasticity¹⁶⁷. Other spasticity altering procedures such as botulinum toxin injections especially into the gastrocnemius muscle as well as orthopaedic tendon lengthening and transfers may have a negative effect on force production. Another common intervention such as the use of orthoses may cause weakness due to prolonged periods of immobility¹⁶⁸.

2.4.2.2 Spasticity and hyperactive reflexes

Spasticity(hyper-reflexia) affects approximately two thirds of the CP population and is characterized by an abnormal increase in the sensitivity of skeletal muscles to passive stretch¹⁶⁹. Spasticity occurs as a result of a loss of inhibitory modulating influences on muscle spindle activity at the level of the spinal reflex arc¹⁷⁰. In CP the muscle groups usually more affected include the flexors, adductors and internal rotators which may contribute to the typical postural and gait patterns seen - for example the crouch gait in diplegia and the equines gait in hemiplegia. Elbow, wrist and finger flexion and forearm pronation, is the typical posturing seen due to increased tone in the upper limb¹⁷¹.

The presence of either hypertonia (increased resistance to passive stretch) and or spasticity in the trunk however is not well described. Ventral trunk EMG used in a study

to assess postural control in children with spastic diplegia⁷² demonstrated that greater co-contraction occurs between ventral (neck flexors, rectus abdominis and hip flexors) and dorsal (erector spinae and hip extensors) muscles during seated weight displacement when compared to normal age-matched peers. Carlberg and Hadders-Algra (2005) suggest that the high degree of co-activation is task-related^{66,72} and represents a strategy to cope with deficient postural control rather than a problem of increased tone.

While muscle stiffness due to hypertonia may be detected in the trunk during slow passive movement, spasticity is difficult to measure accurately and can vary considerably within the same muscle / muscle group¹⁷². The resistance to movement often increases with increasing speed of stretch. Increasing walking speed for example results in increased toe-walking¹⁷³ and associated upper limb movement. It also varies with the direction of movement, for example rotation of the limb or trunk may have an inhibitory effect on the increased tone⁴¹. Furthermore spasticity may be affected by emotion, position or state of readiness⁵¹.

Muscles which present with increased tone undergo structural changes which include variation in size, from relatively minor to very large, and display both atrophy and hypertrophy^{62,174}. Typically the muscle belly is shortened and may exhibit a longer tendon than normal¹⁷⁵. Histochemical analysis also shows change in fibre-type (refer to 2.4.2.1). In normal muscle tissue, subsequent fibre size per muscle is relatively constant and type I and type II fibres are similar in size. Fibre type distribution however does vary amongst different muscles^{176,177}. In spastic muscles however, the prolonged involuntary contraction of the muscle requires more fatigue-resistant type I fibres which leads to abnormally sustained or 'stiff' postures with no or reduced dynamic postural responses. It is difficult for these muscles to initiate a phasic response required for rapid movement¹⁷⁴.

2.4.2.3 *Abnormal range of movement*

Hypo-extensibility and/or stiffness due to increased underlying muscle tone may result in a decrease in range of movement. Secondary complications such as contracture formation and changes in biomechanical alignment further decrease the ability of certain joints to move through their full range of motion. Structural adaptations occur in

the non-contractile tissue such as the ligaments and capsule which also contributes to decreased joint mobility.

Muscle weakness and decreased extensibility in certain muscles may result in hyper-mobility and over-lengthening in other muscles. For example, genu recurvatum occurs as a result of excessive plantar-flexion moment because normal dorsiflexion at the ankle cannot occur due to increased tone in the triceps surae⁸⁷. Alternatively, increased body weight with increasing age may result in increased magnitude of crouch resulting in over-lengthened tendon Achilles despite increased tone in the calf muscles. Lois Bly^v postulates that the exaggerated anterior pelvic tilt so often seen in children with CP is due to inactive postural trunk muscles. This makes hip flexion difficult as the iliopsoas is placed in a shortened position and is not able to generate adequate tension required by the forward swinging leg. The validity of these hypotheses needs to be tested empirically.

2.4.3 Activity and participatory limitations

Children with CP present with certain or typical gait patterns and are generally unable to maintain a typical upright posture, nor use normal movement or balance reactions which may interfere with their ability to function^{49;66;87;119;178}. These difficulties all impact on activities of daily living and effect performance at home, at school and within the broader community¹⁷⁹. Evaluation of a person's ability to participate in a desired societal role in CP however is not well developed and therefore more difficult to classify¹⁷⁹.

2.4.3.1 Upright posture and balance

Postural problems play a central role in motor dysfunction in CP. Everyday activities are influenced by poor trunk control. The extent of the problem varies considerably and its impact on function results in many of these daily activities having to be performed in a sitting position because the child cannot maintain an upright position in standing⁴⁹ or may even be so severe as to result in no standing or walking ability. Even sitting

^v Training course notes, Cape Town 1998

upright independently may not be possible without external support - increasing caregiver dependency for activities of daily living.

Children with CP who can sit can counteract a disturbing force by producing direction-specific postural activity but often this force is insufficient^{66;73}. They have greater difficulty adjusting the muscle activity required to regain an upright posture when balance has been disturbed. Ethical concerns regarding the insertion of wire electrodes have limited description of abdominal muscle activity to the superficial muscles only. EMG of postural muscle activity using surface electrodes has shown a top-down recruitment of muscle activity. Children with CP use their head and neck muscles predominantly and have an excessive degree of antagonistic co-activation⁷³. The 'rigid' trunk makes it difficult for children with CP to move out of their base of support and they do not display the typical balance reactions in the trunk (lengthening on the weight-bearing side and concurrent rotation of the upper quadrant) and limbs (extension). Similarly, when compared to their able-bodied peers children with a crouch gait posture have also shown a decreased ability to recover their standing balance in that it takes longer and they display increased sway of the trunk and upper limb(s)¹¹⁹. Delayed responses in the ankle muscles, inappropriate sequencing, and increased co-activation of the agonist and antagonist was also seen¹¹⁹.

2.4.3.2 Gait

Specific gait patterns emerge, although large variation within these patterns can exist⁸⁷. For example ambulant children with spastic diplegia typically display an asymmetrical crouch gait posture with the hips, knees and ankles in flexion¹⁸⁰. Children with spastic hemiplegia usually display poor hip extension in the involved lower limb and the knee remains slightly flexed or snaps into extension or hyperextension¹⁵⁴. Gait analysis has demonstrated that diplegic children tend to have slower free and fast walking velocities and cadence, shortened stride length, increased double support and decreased single support as compared to their normal peers¹⁶⁵. In hemiplegics, double support time is increased and step length on the involved side reduced as compared to the uninvolved side¹⁵⁴.

The typical foot position in both hemiplegia and diplegia is a plantar flexion deformity or equines foot which impacts on weight-bearing and forward propulsion during gait¹⁸¹. Sixty to 70% percent of the power required for forward propulsion during walking comes from the plantar flexors^{67;87;182}. This plantar flexion position in CP is due to over-

active and or shortened triceps surae which prohibit these muscles from achieving an effective length for generating plantar flexion and toe-off force.

The development and causal mechanisms for these typical gait and postural patterns are not clear. During the development of motor control in CP, the perseverance of immature abnormal movement patterns due to decreased supra-spinal inhibition of primitive monosynaptic activity¹⁹, is reported to be the problem. Furthermore inappropriate sequencing and co-activation of synergists and antagonists^{168;183} impose abnormal forces on the skeleton resulting in the development of abnormal biomechanics⁸⁷. The inability to generate sufficient force or muscle weakness is found to be more severe in certain muscle groups such as the hip extensors and dorsiflexors which also contribute to this typical patterning.

The contribution of weakness in the trunk stabilizers to the gait patterns seen in CP is not clear. Although movement of the trunk may occur and assist in performance, for gait and many other functional activities the role of the abdominal muscles in persons with normal motor development serve primarily to maintain upright posture while the limbs move and predominantly require a low level of activity in all four abdominal muscles⁷⁰. A study by Anders et al. (2007) which describes RA, OI and OE activation patterns in normal adults during walking at different speeds confirms involvement of these muscles in gait function and both phasic and tonic activity is reported¹²³. The authors concluded that although there are differences in individual muscle activation strategies for walking at different speeds, the increasing cumulative effect in the three muscles recorded correlates with increasing walking speed. It remains to be established whether there is activity in the deeper stabilising TrA muscle. Whether these relationships exist in children also still needs to be established.

Children with cerebral palsy walk inefficiently and expend more energy during walking than their able-bodied peers¹⁸⁴⁻¹⁸⁶. An increase in walking speed is usually accompanied by an increase in cadence rather than an increase in stride length¹⁸⁷. The relatively 'stiff' lower limb gait pattern and the exaggerated compensatory lateral sway of the trunk increases the vertical and horizontal excursion of the body's centre of mass, increasing energy consumption¹⁸⁸. These authors speculate that local muscle factors – the decreased motor unit firing rate modulation results in early fatigue and probably represents the single most important reason for the higher O₂ cost in children with CP. They also attribute increased body weight to higher O₂ costs when compared

to their normal peers. Other mechanical properties of the muscles such as increased tone and decreased extensibility in the agonists also increases energy expenditure as these muscles have to work harder to overcome the increased passive resistance^{189;190}.

2.4.3.3 *Impact on activities of daily living*

Many functional problems and challenges are experienced by persons with CP due to the primary impairments as described above and their effects on posture, balance and gait. Functional problems vary from slower speed of execution when compared to their normal or able-bodied peers, to total dependence on a caregiver for all activities of daily living^{191;192}. Children with oromotor dysfunction also experience swallowing, speech and communication problems. External support in the form of wheelchairs, walking aides such as walkers and crutches¹⁹³, orthotics¹⁹⁴⁻¹⁹⁶, adaptive seating devices such as special cushions and inserts¹⁹⁷ and communication devices may be required to enable a higher level of functioning and to reduce care giver strain¹⁹⁸.

According to Rosenbaum et al. (2002), children classified as Level IV - those more greatly affected - according to the GMFCS reach 90% of their maximal motor potential before the age of three, while children in level one - those least affected - probably only reach their maximal motor potential by age five. Generally, hemiplegic children also have a greater potential to walk than those children with a wider distribution of spasticity¹⁹⁹.

Impact in the classroom and the ability to concentrate and learn has also been reported¹⁹⁸. Specific learning problems may be associated with the brain lesion(s), but are also affected by restricted freedom of movement²⁰⁰. Cognition, problem-solving and laterality develop through experiencing the environment. Children with restricted movement have therefore difficulty in processing environmental information and are unable to organize an appropriate behavioural or motor response and present with sensory integration and perceptual disorders²⁰¹. Some children experience difficulty reading, they may struggle with mathematical concepts or have poor memory. A study that investigated the prevalence of specific learning difficulties in 149 children with hemiplegia²⁰² found that 35% of those children had Intelligence Quotient (IQ) scores below 70. The authors also reported that children with hemiplegia, whose cognitive abilities and predicted academic ability were within the average range, had significantly more specific learning difficulties than children with TD, with 36% having at least one specific learning difficulty. Those children with specific learning difficulties had more

neurological impairments and a significantly higher rate of emotional and behavioural difficulties than a group of comparison children. Children with learning problems often experience psychosocial problems which puts them at risk for development of poor self-esteem. Frustration and temper tantrums may also occur.

Competitive employment rates for persons with CP of up to 52% have been reported²⁰³ which have been attributed to the improvement and access of mobility devices such as motorized wheelchairs and computers, environmental access and supportive legislation. In SA, despite improved policy and legislation regarding the disabled community, access to electrical wheelchairs and computers remains difficult. Even in urban special schools children requiring assistive devices for either learning or personal communication have no access to these computers.

The secondary impairments and changes which normally occur across the lifespan which include early onset arthritis and pain can be expected to be more severe in this population and further escalate these challenges. Loss of function such as a decline in mobility or ease of mobility, ability to negotiate stairs, navigating safely over uneven terrain, propelling wheelchairs and performing activities of daily living are reported^{30;36}.

2.5 Intervention strategies

CP continues to be the most common neurological childhood disorder and the incidence might even be increasing (refer to 2.3.2). The evidence suggests early intervention has more favourable outcome although ongoing rehabilitation is required due to the secondary complications that occur in this population²⁰⁴. Many treatment strategies have been developed but results are equivocal and the evidence to support any specific intervention lacking²⁰⁵. The central nervous system (CNS) has a considerable capacity for compensatory and adaptive strategies^{19;206} which may account for not only the variation in clinical presentation but for the broad spectrum of response to treatment as well.

There are many approaches to the (re)habilitation and treatment of children with CP. The traditional or typical approaches include Neuro-developmental therapy (NDT)²⁰⁷, conductive education (CE)²⁰⁸, the Vojta Concept²⁰⁹ and Doman-Delecatto Method²¹⁰. An improved understanding of the underlying pathology and development of motor

patterns in children with CP^{50;163;211;212} however suggest that specifically targeting the primary impairments resulting from the brain lesion i.e. reducing spasticity²¹³⁻²¹⁵, strengthening weak musculature^{40;89} and correcting biomechanical malalignment²¹⁶ can improve not only cosmetic appearance, but also significantly impact function and the more recent approach to rehabilitation of persons with CP tends to combine the traditional approach with more impairment targeted intervention techniques. These include, but are not restricted to: strength training^{40;89}, constraint induced therapy^{10;217;218}, treadmill training²¹⁹⁻²²¹, therapeutic and functional electrical stimulation^{38;222-230}, reactive balance training^{47;74}, and surgical and or orthopaedic intervention^{43;74;159;213;214;216;231-233}. Alternative treatment options include hippotherapy^{234;235}, hyperbaric oxygen therapy²³⁶ and acupuncture²³⁷⁻²³⁹.

While therapeutic intervention aims to optimize function primarily by improving internal factors, making use of assistive devices may further enhance these goals²⁰⁵. These devices include augmentative communication devices¹⁹⁸; postural support and seating systems^{240;241}; mobility devices such as crutches, rollator and wheelchairs^{193;242;243}; and orthotics, splints and casts^{196;244;194;245;246}. Persons with CP may use one or many devices at a time and the type of device may vary throughout the lifespan.

While a more detailed description of each of these interventions can be found in Appendix 1, this section of the review is limited to the literature pertaining to intervention targeting the trunk. As muscle weakness seems to be a significant contributor to poor postural control and forward propulsion (refer to 2.4.2) strength training will also be discussed.

2.5.1 Strength training

Despite the ongoing debate regarding the contribution of muscle weakness to the motor dysfunction seen in spastic-type CP, there is increasing evidence stating that weak muscles can become stronger, with a low to moderate effect on function^{88;247}. Haney (1998) stated in her review article that as early as 1958 studies have demonstrated resistance or weight training (progressive resistance exercise or PRE) to be effective in children with CP without apparent increase in spasticity. Furthermore,

these children appear to gain strength at the same rate as persons with weakness without central nervous system pathology^{248;249}.

Initial studies investigating the effect of strength training programs mainly targeted the weaker muscle groups – the extensors of the lower limb and included the knee and/or hip extensors and plantar flexors^{90;92-94}. Their programs demonstrated an increase in targeted muscle strength, stride length and/or a decrease in the degree of crouch. Functional gains as scored by the GMFM were also reported. The clinical relevance of these changes in impairment and level of activity in children with CP, as well as the long term effects and possible side effects however has been rarely investigated.

The effect of more comprehensive strength-training programs targeting multiple muscle groups has also been investigated and although not comparable with any of the above studies, did not appear to report larger effect sizes regarding strength gain and impact on gait. The current evidence however should also be interpreted with caution as most studies investigating the effects of strength training in the CP population are of single group design and effect sizes reported cannot conclusively therefore be attributed to the strengthening intervention alone. Two randomized controlled trials (RCT) investigating the effects of strength training in children⁹² and adolescents⁴⁵ could only demonstrate significant improvement in muscle strength when summing the strength measurements for all the muscles tested. Individual muscle strength measurements showed no significant change in strength for the experimental group when compared to the control group post intervention. However both studies did report trends for improved strength and function and the authors attributed the relatively small effect size to the small sample size, the short duration of the program as well as the lack of supervision and possible contamination of the control group.

Unger et al. (2006) hypothesized that inclusion of the trunk muscles in their strength training program would result in a larger effect size on lower limb functional performance as a stronger trunk may result in better pelvic positioning and stability⁴⁵. As trunk strength was not measured objectively and no comparison without inclusion of trunk strengthening exercise was made, this hypothesis remains unchallenged. The type of exercise selected for strengthening in the above mentioned study however included mainly isotonic muscle activity and these were prescribed in accordance with PRE progression principles. No specific exercises aimed at recruitment or

strengthening of the transversus abdominis and or obliquus internus as stabilizers were included in this study. Stackhouse et al. (2005) suggested that because children with CP demonstrate large deficits in voluntary muscle activation using voluntary contractions for strength training may not produce forces sufficient to cause muscle hypertrophy⁶⁰. Currently there is no description of activity or the absence thereof in the four abdominal muscles in children. While younger children with TD may also present with restricted abdominal muscle functioning²⁵⁰ without normative values which describe recruitment patterns and level of activity in these muscle it remains unknown which facilitation techniques and strengthening exercises should be prescribed.

A more recent systematic review confirmed that lack of methodological rigour limited the findings related to strength training and although the authors concluded that there is no evidence that strength training is safe or effective in persons with CP¹⁶, they did acknowledge that the increase in muscle strength in various muscles varied hugely among individuals - strength gains were reported between 0 and >200% for selected muscles. The authors of a RCT in the adult CP population postulated that weakness as a secondary complication responds better to strength training than weakness due to the primary impairment²⁵¹. This apparent discrepancy among individuals in treatment response following progressive resisted exercise warrants further investigation. Renowned researchers in the field of strength training in CP, including Drs Eileen Fowler and Diane Damiano also recommend that because of the complexity of the diagnosis when interpreting outcome in studies investigating effect of intervention on CP-related impairments, it is done within the context of broader health considerations³⁹ (refer to 2.6) - and include investigation into the influence of the environment; an individual's level of motivation to participate in strengthening programs; accessibility to gym training facilities; co-morbidities etc.

Feasibility for implementation of strength-training in a variety of settings has been reported. Community-based gym²⁵²⁻²⁵⁴ for adults and adolescents, school-based progressive resisted exercise⁴⁵ and circuit training²⁵⁵ as well as home-based programs for young children⁹² have been investigated. Although it has been hypothesized that participation in more normal settings or among peers contributes to better outcome and compliance, these settings did not appear to affect outcome in terms of effect on muscle strength or function. However it was reported that gym training in a community health centre or school-based group work was perceived as being enjoyable and contributed to improved functional competence^{42;253} – aspects which cannot be ignored

and may contribute to better and ongoing compliance. Investigation into barriers and facilitators for ongoing exercise compliance as well as long term follow-up of these subjects is required.

2.5.2 Interventions targeting the trunk

Most interventions aimed at reducing spasticity, improving biomechanical alignment and strengthening weak muscles target the limbs and seldom make specific reference to targeting the core or trunk musculature. A randomized control trial however investigating the effect of an eight-week progressive resisted exercise program in circuit format in adolescents with STCP included abdominal and back extensor exercises⁴⁵. The authors reported that inclusion of the trunk in their exercise program did not result in 'better' gait performance compared to outcome reported in studies investigating only lower limb targeted strengthening programs. This despite apparent increase in abdominal muscle strength as measured by the change in the number of independent sit-ups executed. Similarly total body circuit training at a local gymnasium resulted in improved lower limb function in adults with CP⁴⁴. Although exercises targeting the trunk were included, neither the effect on abdominal muscle strength nor the impact strengthening the trunk had on lower limb function was discussed.

Park et al. (2001) investigated the effect of the application of electrical stimulation to the abdominal and back musculature in six to 18 month old infants²²⁵. The authors reported a significant improvement in a sitting posture and trunk control using radiographic imaging when compared to a control group. Another article, a summary of six single case studies, reported on the effect of a trunk targeted intervention in children aged two to seven who could not sit independently⁷⁴. A special supportive structure was designed and positioned on an antero-posterior movable platform. All six children in the study achieved independent sitting balance within ± 16 months. This study however had no control group and the impact of the intervention may have been overestimated. No further studies investigating this approach have since been published and external validity is questioned.

Other interventions such as therapeutic horseback riding have also reported improved posture and balance in children with CP. Bertoti et al. (1988) using a self-designed postural balance scale reported significant improvement in posture as well as clinical

improvements in lower limb muscle tone and balance in children aged two to nine years old²³⁴. A more recent single blinded, case controlled study in children with CP reported significant improvement in function (i.e. GMFM total scores) immediately following hippotherapy intervention²⁵⁶. These improvements however were not maintained and GMFM total scores returned to baseline six weeks after the riding therapy had stopped. There was however a carry-over effect reported for Dimension E of the GMFM (walking, running and jumping) at six weeks post-intervention. The above studies however are all relatively low level ranked, either without control or subjects served as their own control, sample sizes were small and except for the GMFM, reliability of outcome measurements used is questionable.

The concept of reactive balance retraining by intensive practice in response to balance threats while standing on a movable platform has also been investigated in a group of school going children⁴⁷. The study reported that such a program resulted in significant improvement in these children's ability to regain balance and when assessed on the GMFM, improvement was noted in three out of the five children, for dimension D – quiet stance and anticipatory balance skills. Impact of this intervention on other functional activities was not assessed. The authors reported more efficient timing of co-contraction, shorter muscle contraction onset i.e. reacted quicker; and reduced co-contraction of the agonist/antagonist. They attributed these changes to improved proprioceptive sensitivity, enhanced synaptic activity in the sensorimotor cortex pathways or possibly due to higher level adaptations at the level of the cerebellum or association cortex.

The more 'traditional' techniques used by physiotherapists to facilitate activity in the limb musculature include exteroceptive- and proprioceptive stimulation such as ice brushing, tapping - use of stretch reflex²⁵⁷, compression and distraction²⁵⁸, shaking and manual vibration²⁵⁹. Some of these techniques can be applied to the abdominal muscles but the stimulation is limited to the more superficial rectus abdominis and obliquus internus muscles. The evidence for efficacy in facilitating recruitment of the deeper underlying stabiliser muscles such as the transversus abdominis is not well described.

Description of interventions targeting the trunk in children, both with and without pathology, is scarce. There is some evidence that trunk muscles of children with CP

can become stronger and that their control mechanisms can be altered although the level at which these changes occurred is still speculative.

2.6 Outcome measures and outcome evaluation in children with CP

Bartlett and Palisano's proposed multivariate model of determinants for motor change in children with CP²⁶⁰ highlight the complexity of decision making regarding intervention when the primary aim is to impact motor outcome. Primary impairments due to the brain lesion may strongly influence changes in motor abilities in association with secondary impairments. Not only should these impairments be assessed, but also interpersonal and environmental factors need to be evaluated and monitored throughout the treatment and rehabilitation process. Various standardized outcome measures have been developed to assess the impact of these primary and secondary impairments on functional ability, quality of life and perception of body-image and functional competence. However as this review is directed at impairments and their impact on functional activity in relation to the trunk, this section is limited to a discussion on measures for the assessment of gross motor function in older children, strength assessment measures and instruments for detecting muscular activity in particular the abdominal muscles.

2.6.1 Measurement of gross motor function in older children

Several outcome measures have been used to describe gross motor function as well as evaluate efficacy of intervention(s) targeting gross motor function in the paediatric CP population. According to Ketelaar et al. (1998) the only two measures however that fulfil the criteria of reliability and validity with respect to responsiveness to change, are the Gross Motor Function Measure (GMFM) and the Paediatric Evaluation of Disability Inventory (PEDI)²⁶¹. These findings are corroborated by a more recent publication in which the authors compared several outcome measures to the GMFM regarding their ability to reliably discriminate between levels of function²⁶².

The GMFM-88 and later the GMFM-66, a criterion-referenced observational measure were designed and validated to evaluate changes over time in children with CP aged five months to 16 years of age^{5;199} and is the most widely used measure for the detection of change in motor function in the CP population. This scale used in conjunction with the Gross Motor Function Classification System (GMFCS) - a five level scale classifying persons with CP in accordance with their level of functioning²⁶³ - enables therapists together with the child and his/her family to collaborate and formulate goals which are consistent with the child's potential²⁰⁴. The GMFM however does not measure components of health such as movement efficiency, wheelchair mobility performance and physical fitness.

The Paediatric Evaluation of Disability Inventory (PEDI) is also widely used in the younger paediatric CP population and measures capability and performance in self-care, mobility and social function in children between six months and seven and a half years. The amount of help required from the caregiver and the equipment needed is also recorded. The GMFM and PEDI measure different aspects of function but could be used to supplement each other²⁶⁴.

Other standardised measures have been developed to measure more specific domains of gross motor function for example for balance and gait. As these instruments are impairment or activity specific, they tend to be more responsive to changes within that particular attribute.

2.6.1.1 Gait analysis

Walking is the most fundamental means of moving about for the great majority of people²⁶⁵. The ability to mobilise in any direction and transfer into and out of various positions requires a complex combination of neuro-musculoskeletal activity and positioning requiring simultaneous movement of all four limbs. There is also movement of the vertebral column. Analysis of various gait parameters - temporal distance and pelvic and / or lower limb angular kinematic data - is most often assessed in order to determine effect or impact of an intervention on function as changes in gait are often associated with improved performance in other activities of daily living^{229;266}. In the paediatric population with CP Damiano and Abel (1996) showed that correlations exist between selected gait variables and GMFM total scores⁹¹.

Various gait outcome measures are used including observational gait analysis and videography or two dimensional gait analysis (2-D GA). While observational measures have shown good to moderate reliability for assessing selected gait distance parameters²⁶⁷, 2-DGA methods can also be used to measure joint angles. These however need to be interpreted with caution as slight rotation of the body around the vertical axis can result in measurement error²⁶⁸.

The gold standard currently used for the measurement of reliable distance parameters such as stride or step length, as well as joint kinematics is three dimensional gait analysis (3-D GA)²⁶⁹. Cadence and velocity and measurement of joint angles can be calculated using 3-DGA and computer software programs. There is however some discrepancy in the literature regarding intra-subject repeatability in the population with CP. Steinwender et al. (2001) found GA to be a valid and reliable measure although the authors reported repeatability to be better amongst typically developing children¹⁸⁰. Another study reported substantial variation in raw data when the same subject was assessed at four different motion laboratories²⁷⁰. Despite these findings several researchers still consider 3-D GA to be a reliable outcome measure for accurately detecting change following intervention in the population with CP^{91;253;271}. As many interventions utilising gait as an outcome measure predominantly targeted the lower limbs, analyses of gait parameters were also restricted to lower limb kinetics and kinematics. Description of truncal kinematics during walking is lacking although one study did infer truncal movement from changes in position of the centre of mass (COM)¹²². Few studies in adults have shown significant correlations between truncal angular measurements and gait distance parameters – a study in runners showed that with increasing speed, movement in the trunk increased in terms of obliquity, antero-posterior - and vertical displacement in relation to the pelvis²⁷². In this study trunk movement was analysed as one fixed segment.

At the onset of the study 3-D motion analysis systems in Cape Town were laboratory based with restricted accessibility. In the absence of a gold standard measure such as a 3-D motion analysis system various alternative clinically more feasible methods are advocated for use in the paediatric population with CP. These measures however are all limited in their assessment in that typically only one aspect or component of gait is assessed. One example is the measurement of walking speed with the help of a stopwatch. Another measure of gait speed is the fast one minute walk test described by McDowell et al. (2005). This test is considered a valid descriptor of functional ability

and has shown good correlation with both GMFM-88 ($r=0.92$) and GMFM-66 ($r=0.89$) with similar correlation for the dimensions D (standing) and E (walking, running and hopping)²⁷³. The test has also been shown to have a significant moderate relationship with energy efficiency of gait using a five minute O_2 -cost protocol²⁷⁴.

Abnormal gait patterns in CP are commonly associated with increased energy expenditure (refer to 2.4.3.2) and although not a measure of gait, energy expenditure during gait is often measured and used as an indicator of improved gait performance. Sophisticated computerized O_2 and CO_2 breath analysis has been used during free walking^{185;186} and walking on a treadmill^{189;275}. The Energy Expenditure Index (EEI), also known as the Physiological Cost Index (PCI) - a score based on heart rate - is a reliable and clinically more convenient method to determine energy costs in children with CP¹⁸⁵.

A more subjective measure of gait is the Gillette Functional Assessment Questionnaire (FAQ). This measure has been used in CP research and is a 10-level parent-report measure that audits a range of walking abilities in all community settings and terrains. It is a reliable and valid measure specific but only to the task of walking²⁷⁶.

2.6.1.2 Balance outcome measures

In paediatrics, force plate data⁴⁸, other lab based tests such as one leg standing and functional reach tests²⁷⁷ and timed get-up-and-go test (TUG)²⁷⁸ are used to measure standing balance but only at the level of impairment²⁷⁹. Similarly the Trunk Impairment Scale (TIS) - a tool originally developed in order to measure seated static and dynamic balance in patients with stroke²⁸⁰ - can be used in children in that reliability has been proven²⁸¹, but as yet this outcome measure has not been correlated with balance in standing and or activity of daily living in the population with CP. Children with CP or other motor abnormalities or delays may have acquired basic functional abilities, but have a limited repertoire of movement strategies for different circumstances e.g. lack endurance to maintain posture or are only able to turn in one direction etc. While there are more comprehensive measures of gross motor function in paediatrics such as the Bruininks-Oseretsky Test of Motor Proficiency-2²⁸² and Peabody Developmental Scale²⁸³ which include balance sub-scales, these have been criticised for the lack of responsiveness to detect change²⁸⁴. Although force plate data and TUG have shown better reliability²⁸⁵, the paediatric balance scale (PBS) was developed for school-aged children in order to determine a child's functional balance ability in activities of daily

living. Franjoine et al.(2003)adapted the Berg Balance Scale - a valid and reliable balance outcome measure commonly used to predict risk of falling in the elderly²⁸⁶⁻²⁸⁸. The paediatric version or PBS consists of 14 items ranging from sit to stand to reaching forward with outstretched arm and includes activities such as tandem standing, standing on one leg and picking up an object off the floor²⁸⁹.

2.6.1.3 Tests for measuring core stability

The complexity of spinal stability and the high incidence of low back pain (LBP) in adults worldwide have led to researchers developing test batteries aimed at assessing the various components of functional stability of the lumbar spine. Typically a combination of isometric contractions in various positions and/postures for example back extension, trunk flexion and left and right side bridging¹¹⁴- is used to test for core strength. For evaluating the impact of core strength training some researchers have added functional performance tests¹⁰² which - as most of this research has been conducted in the field of sports performance - include vertical jump, broad jump, shuttle run, maximum rowing test etc. These tests however only evaluate the contribution of a single factor - i.e. isometric strength -to good postural control and core functioning.

A more comprehensive test developed by Stevens et al. (2006) aims to assess the passive structures of the spine, muscle functional characteristics, neuro-muscular control as well as postural control²⁹⁰. Postural control is assessed using sway velocity data produced during unilateral stance on a force plate; proprioception is determined by measuring position-reposition accuracy of the lumbar spine; various exercises (including isometric contractions, coordination, stabilisation with limb movement and stabilisation with trunk movement and endurance) test various components of strength. While this test has shown good test-retest reliability in healthy adults, reliability in persons with pathology (pain) has been questioned²⁹⁰. When dealing with pathology more in depth evaluation of behaviour, internal- and environmental factors must be taken into account to more accurately interpret findings.

The Sahrmann core stability test²⁹¹ using a stabiliser pressure biofeedback unit is also commonly used in rehabilitation practice to evaluate trunk muscle stability function⁹⁶. Several studies however did not record improvement in test parameters while significant improvement in balance stability was observed^{292;293}. Although the authors postulated that the intervention program may have had a bigger impact on other

contributing muscles which were not evaluated in their studies, the responsiveness of this test could be questioned.

While several tests have been developed for assessing balance and motor control, no battery tests which collectively analyse strength, endurance and motor control have been described for global assessment of core stability in children.

2.6.2 Methods for testing muscle strength

There are four generally accepted (valid and reliable) methods to test muscle strength⁶⁸ and the use of each is well described by McArdle et al. (1996). These methods include: cable tensionometry which measurements isometric muscle force; static or hand-held dynamometry, also used for static strength measurement; one-repetition maximum (1-RM), which refers to the maximum amount of weight lifted one time with correct form; and computer assisted and electromechanical and isokinetic methods, which are able to quantify forces, torques and accelerations and velocities of body segments in various movement patterns. Although criticised regarding inter-tester reliability manual muscle testing such as the 5-scale Oxford and Kendal grading systems are also used as a methods for measuring muscle strength. Manual methods of muscle testing however is tester dependent and is not responsive enough to detect small changes in force generation⁹⁹.

2.6.2.1 Dynamometry

Dynamometry either using handheld or isokinetic devices is well used for testing muscle strength in the CP population^{45;90;92-94;255;294;295}. Computer-assisted isokinetic dynamometer is the preferred form of muscle testing as both torque and active range of movement are measured. Testing of lower limb strength using isokinetic devices (Cybex) is reliable for use in children with CP^{94;296}. There is however uncertainty regarding the most appropriate velocity for isokinetic testing of persons with cerebral palsy due to the effect speed has on spasticity. It has been reported that subjects experience difficulty in understanding how to resist the resistance pad of the isokinetic dynamometer especially during the eccentric muscle action^{94;252}. Isokinetic devices are expensive and not always feasible to use in the clinical setting. Hand-held dynamometry has been well correlated with isokinetic devices²⁹⁷ and found reliable for testing isometric muscle strength in children with CP^{93;298}.

All of the above devices are primarily used for testing upper and lower limb strength. Dynamometry is described in the literature and used for testing global trunk movement i.e. trunk flexion, extension^{75;299}, but due to the anatomy of the trunk musculature, most of the muscles expand over multiple joints and overlap extensively, making it difficult to isolate each muscle in order to independently determine its contribution to the movement. Reliability of isokinetic devices has been questioned and to the knowledge of the researcher their use in children for measuring abdominal muscle strength is not described. Although hand-held devices have been used to determine abdominal muscle strength, the authors of these studies question reliability due to the variation found with repeated attempts^{115;300}.

2.6.2.2 *Field tests for measuring abdominal muscle strength*

Field performance tests are commonly used to investigate impact following strength training³⁰¹. Changes or an increase in muscle strength is typically inferred from these performance measures. As the name suggests these tests are performed in the field and are often the preferred means for interpreting strength gains as opposed to less accessible laboratory-based isokinetic devices. These measures test more than (by definition) muscle strength or 1RM and include muscle performance components such as power and/or endurance and/or motor control. The total number of sit-ups executed in one minute for example, often serves as a proxy of abdominal muscle strength and endurance^{302;303}.

2.6.3 *Methods for detecting activity in muscles*

Electromyography and more recently diagnostic ultrasound imaging are instruments used for detecting, recording and interpreting activity in muscle.

2.6.3.1 *Electromyography (EMG)*

EMG recording is used to detect responses in timing of muscle activity onset and duration, in sequencing of agonist and in co-contraction of antagonists. Motor unit firing rate and modulation of firing rate can be monitored. In the adult population the use of electromyography (EMG) is widely reported and includes description of its use for investigating trunk muscle activity. EMG has been used to investigate response of the trunk muscles to perturbation of the trunk^{107;304;305}, perturbation of the upper limbs¹⁰⁴ as

well as during activities of the lower limbs⁷⁸. Insertion of fine-wire electrodes into the muscles - usually with the help of ultrasound imaging or electrical stimulation^{306;307} - is preferred as surface electrodes are unable to reliably detect activity in the deeper muscles³⁰⁸. The disadvantage of surface electrodes is that all activity is monitored by the electrodes and therefore may also detect activity in the deeper muscles as well⁷⁶. Marshall and Murphy (2003) however showed that surface EMG activity in adult transversus abdominis and the obliquus internus muscles can be recorded reliably³⁰⁹ and another study investigating trunk muscle activity during axial rotation exertions also demonstrated reliability in the rectus abdominis and obliquus externus muscles³¹⁰.

Investigating muscle activity using EMG in paediatrics is less well described. Researchers seldom provided 'local evidence' that the test is valid and actually measures what it is intended to measure for a particular purpose in this population³¹¹. Secondly motor patterns and performance may vary across repeated attempts or from session to session because of aspects such as learning effect or fatigue. This variance could be expected to be more in the younger paediatric population and may affect repeatability of the measurement. A study investigating reliability for the use of surface electrodes during gait³¹² suggest careful interpretation of outcome due to the increased variability found within-session repeated measurements when compared to adults. This variability makes accurate detection of change over time difficult as any real change that took place as a result of growth or following intervention for example can, or will be obscured by the noise introduced by the measurement error.

Despite these limitations however EMG has been and is used to better describe strategies for forward propulsion and force generation during gait^{56;168;294;313-316} and strengthening programs^{55;168} as well as for better understanding seating^{73;317} and standing balance^{119;178} strategies in children with CP. In these studies surface electrodes were used to detect and monitor muscle activity in selected muscle groups. Although fine wire electrodes were used in children before 2000³⁰⁸, no studies in the last decade could be found which used these electrodes in children. Generally research ethics committees do not approve studies that involve invasive techniques in children which are uncomfortable and may potentially be dangerous due to the small muscle bulk, without appropriate analgesia or anaesthetics. Apart from the ethical concerns, suppressing consciousness would render investigating voluntary muscle work impossible.

Surface electrodes have also been used in children for describing trunk muscle activity, but studies have limited their investigation to the rectus abdominis and erector spinae muscles^{48;178;318}. Accurate placement of surface electrodes on the abdominal muscles in children may be very difficult because although anatomically abdominal muscles in children are presumed to be a smaller version of adult anatomy, no evidence in the literature for this could be found. Accurate placement of the electrodes to avoid interference from surrounding muscles may therefore be difficult if not impossible. No evidence for reliable use of surface EMG for investigating abdominal muscle activity in children could be found.

2.6.3.2 *Ultrasound imaging (US)*

Ultrasonography can also be used to investigate muscle activity and in the field of adult orthopaedics is increasingly being used for investigating truncal muscle activity - for both diagnostic^{77;78;80;81;319;320} and rehabilitative^{116;321;322} purposes. US imaging of the abdominal muscles has been shown to correlate with more sophisticated diagnostic imaging systems such as magnetic resonance imaging³²³. US imaging has been used in CP, its application has been limited to describing muscle architecture primarily for investigating the effect of spasticity on muscle morphology^{63;159}. No evidence however for valid and reliable use of US imaging for detecting and investigating muscle activity in the abdominal muscles in persons with CP was found.

With US high resolution grey-scale images of the body are displayed³²⁴. These images are formed by the reflexion of acoustic energy from interfaces within the body. From the images produced various parameters can be measured or calculated. When US imaging is used to describe muscle architecture the typical parameters would include: fascicle angle and length, diameter or thickness, circumference; and with 3D imaging cross-sectional area also can be calculated^{63;158;159}.

Instrumentation³²⁴

All US scanners have the same basic components: a transmitter, a transducer (produces the US waves) and a processor which detects and amplifies the back-scattered energy and manipulates the reflected signals for display forming an image which can be recorded and stored. These signals can be displayed in several ways – M-mode: used in the evaluation of rapid motion; and B-mode: used to produce a single 2-D image (≈a representation of the echoes arising from the object being scanned). B-

mode is the most common method for imaging throughout the body and allows for assessment of anatomy and motion. Images are formed at 15-60 frames per second. As the images show the state and motion of the organ or structure, the information shown is considered to be in 'real-time'.

The transducer (or US head) uses piezoelectricity to produce the high frequency sound waves and can be transmitted in several ways or arrays. Linear rays are commonly used for smaller parts. A series of parallel pulses are generated forming a line of sight perpendicular to the face of the transducer which can be manually focussed at selected depths. Curved arrays allow for a wider field of view and are typically used to scan a larger field of view.

The size (frequency) of the transducer head is determined by the depth of the organ or structure to be viewed. Higher frequency (7.5 – 15MHz) US can penetrate within 1 – 3 cm from the surface, while lower frequencies (2.25 – 5.5 MHz) can be used to evaluate deeper structures, 12 – 15cm from the surface.

Safety of US imaging³²⁵

US imaging is one of the fastest growing imaging modalities due in part to its relatively low cost, provision of images of real-time interactions and lack of bio-effects. Although US can produce heat in the tissues, apply radiation forces on structures, cause motion of fluids (acoustic streaming) and bubbles (acoustic cavitation), these effects are minimal and of temporary duration and generally considered to have no side effects in the person being scanned or the scanner. Correct selection of scanning parameters – modes, frequencies and correct technique ensure safe application.

Validity and reliability for detecting muscle activity

The validity of muscle thickness measurements for accurately detecting activity in the muscles as well as test-retest reliability has been extensively explored specifically in relation to the stabiliser function of the abdominal muscles^{78;80;320;323;326;327}. Changes in thickness measurements (the difference between resting thickness measures and during contraction) of transversus abdominis, obliquus internus and externus have shown a strong to moderate correlation with sub-maximal static and dynamic contractions^{320;326;328} although there is some discrepancy regarding reliability of US for measuring change in thickness in the obliquus externus muscle^{83;329}. Valid US

assessment of muscle thickness changes in other trunk core stabilisers - multifidus^{310;330;331} and pelvic floor³³² - have also been documented in the literature. Currently no description of this instrument for investigating trunk muscles in children could be found.

Ultrasound imaging requires a combination of skills – the user must understand the fundamentals of sound energy and its interaction with tissues in order to optimise the display³²⁴. Radiologists are typically trained in the use of ultrasonography, but US imaging has also been used by rehabilitation therapists for diagnosing and rehabilitating muscle function of particularly the trunk (core) muscles^{321;322}. If shown to be a valid instrument for the measurement of abdominal muscle thickness in children which demonstrates both inter-rater and intra-rater reliability, ultrasound imaging of abdominal muscle thickness could provide a feasible, non-invasive measurement for the description of activity in the abdominal muscles in all children with and without motor disorders.

2.7 CP and the South African context

Although it is encouraged that children with disability are mainstreamed into the public (or private) schooling system, in SA special schools exist which cater for all learners with special education needs. As public schools are typically multi-storey buildings access to classrooms and other facilities are restricted and therefore children with physical disabilities still predominantly attend special schools. Therapy services are typically available although the therapists based at these schools do render a service to the broader surrounding community and provide ongoing care to ex-learners from that school. Children attending special schools do follow the main stream curriculum and would be regarded as being within the average range of cognitive ability.

Figures reported by the CP clinic at Red Cross Children's Hospital suggest that the incidence of CP is increasing in SA. Despite this rise in prevalence, resource restraints such as too few therapists and inadequate facilities, warrant ongoing investigation into more cost and time effective rehabilitation strategies for children and adults with disability. A better understanding therefore of the development of movement strategies and factors influencing these strategies will enable therapists to make better choices

regarding the management of their patients and the communities from which they come.

2.8 Conclusion

It is evident from this literature review that there is a lack of empirical description regarding the nature of the impairments with regard to trunk and its contribution to lower limb function in children with CP. Current interventions are aimed at restoring function by targeting the primary impairments of spasticity, weakness and motor control in the limbs. Little attention has been given to the trunk and considering the importance of core stability forming the basis for controlled movement to occur as well as its role in preventing lower limb injuries, warrants further investigation into the role of the trunk in children with cerebral palsy.

Due to the complexity of measuring activity in the abdominal muscles, the use of ultrasound imaging for this purpose in the paediatric population needs to be explored. Although there are more sophisticated imaging systems US imaging is a much cheaper option, particularly when the anticipated participants are school children. The advantages of increased responsiveness of instruments needs to be balanced against the difficulties in obtaining parental and school permission to recruit participants who will be required to take time out of lessons to travel to another facility for testing on a regular basis. The reliability and validity of field testing instruments such as US imaging, the 1-minute walk test, 2-D photographic analysis, and number of sit-ups executed in one minute would indicate that the use of these instruments is both feasible and valid.

It is the contention of the researcher that ultrasound imaging of the trunk musculature and analysis of the kinetics and kinematics of the standing posture and of gait will allow for the development of more appropriate and effective intervention techniques which are likely to be targeted at improving the strength and activation patterns of the postural muscles.

The validity and reliability of ultrasound imaging for the measurement of abdominal muscle thickness in children

3.1 Introduction

It is evident from the literature review that the incidence of children presenting with motor dysfunction ranging from minimal developmental coordination disorder (DCD)^{333;334} to the more severe types of cerebral palsy (CP)^{27;135;137} presentations is increasing (Chapter 2). These children present with abnormal postural control - lack of core stability and loss of freedom of movement – reasons frequently cited as one of the main contributing factors to the motor dysfunction seen^{49;50;73;178;206;211;317;335-339}. As most activities rely on core stability and the ability to provide a stable base of attachment for the limbs, effective abdominal action is essential³⁴⁰. Description of the functioning of these muscles is predominantly inferred from observational movement analysis because measurement of strength and activity is difficult and the evidence for valid and reliable use in children is lacking (refer to 2.6). As such their contribution to core stability, balance and motor performance is not always clearly or fully understood.

While it is difficult to measure strength and activity in the abdominal muscles ultrasound imaging (US) is increasingly being used for diagnostic and rehabilitative purposes in adults^{80;116;319;341;342}. The use of US however for investigating abdominal muscle activity in children still needs to be determined. Although US is typically applied by radiologists with specific expertise in the field of imaging, this study aimed to explore the reliability of the use of US by physiotherapists who had undergone basic training in the use of the US imaging machine. The need to establish reliable use by therapists is essential if it is to be used as a clinical outcome measure and to monitor change during intervention.

3.2 Aims and objectives

This two part descriptive correlational study therefore aimed to determine the feasibility, reproducibility and repeatability of abdominal muscle thickness measurements using US imaging in children aged six to thirteen years old. In Part 1 the specific objectives of the study were, in a group of typically developing primary school children aged six to thirteen:

- to explore the agreement of the measurement by establishing whether there was a significant correlation between testers (inter-tester reliability) and within testers (intra-tester reliability)
- to examine the discriminative validity and responsiveness to change of the measurement by establishing whether there is a significant difference between resting and contracted thickness
- to determine the convergent validity of abdominal muscle thickness measurements by examining the relationships between muscle thickness and gender, age, weight and height in that it might be assumed that older children with higher body mass index (BMI) might have thicker muscle bellies

Should US imaging be a valid (i.e. able to reliably discriminate between resting and sub-maximal activity thickness measurements) and a reliable measurement of abdominal muscle thickness (in terms of inter- and intra-rater reliability) in children with TD the specific objectives of Part 2 of the study, were in a group of children with CP also aged six to thirteen:

- to explore the stability (as measured by test-retest reliability) of the measurement across time by establishing whether there was a significant correlation between days (between-day reliability) and within day (within-day reliability)

Additional objective:

In both children with TD and children with CP, an additional objective was:

- to establish what the smallest real difference (SRD) is - i.e. determine the magnitude of difference that represents a real difference between two readings

as opposed to the variation in measurement when measuring abdominal muscle thickness

3.3 Methodology

3.3.1 Study design

As this study aimed to determine the relationship of a particular variable among a particular sample, namely abdominal muscle thickness measurements in primary school children, a descriptive, correlational study design was utilised (Statistica, Version 8). Validity and inter- and intra-tester reliability was investigated in children with TD, while the utility of abdominal muscle thickness as an outcome measure was investigated in children with spastic type CP.

3.3.2 Subjects and sampling

A cluster sample of convenience was used in that all subjects were recruited from three local schools. Children with TD were recruited from one public and one private school and children with CP were recruited from one school which caters for learners with special education needs. All the children from these schools who met the following eligibility criteria were invited to participate in the study:

- present on day of testing
- were between the ages of six and thirteen years old

Children who were not well on the day of testing (through self-report) and those with a body mass index (BMI) $>25\text{kg/m}^2$ were excluded from the study. The high BMI was included as an exclusion criterion for the following reason: the distance from the skin to the underlying abdominal musculature in children with a high BMI exceeds that which allows for an image to be recorded which allow for accurate thickness measurements. The fascia boundaries of the muscles are unclear and images sometimes blurred if there is excess adipose tissue. Although the focal distance of the US machine can be altered allowing for deeper visibility, sensitivity of the machine calliper positioning and therefore also the accuracy of the measurement, decreases. It is also difficult to maintain the same position of the transducer on the skin during head or limb activities.

In addition to the above, children with CP had to meet the following criteria to be included in the study:

- present with either spastic diplegia or hemiplegia as diagnosed by the school paediatrician
- ambulant with or without a walking aid or with or without orthoses
- classified by the researcher as either Level I, II or III according to the Gross Motor Function Classification Scale (GMFCS)^{5;192}

Children with TD were also excluded from the study if they had any recorded diagnosis affecting motor function such as developmental coordination disorder, attention deficit and hyperactivity disorder etc. Children with CP were excluded from the study if they had any other diagnosis affecting motor function such as athetosis, ataxia or dystonia. Any potential participants who had surgery or any spasticity altering procedures within the previous twelve months were also excluded.

A power analysis suggested that a minimum sample size of 20 in each group (TD and CP) would be required to detect a correlation coefficient of at least .70 with 95% power and a probability (Alpha) of .05 (Statistica, Version 8). However, as the intention was also to explore the difference in muscle thickness over the different ages in children with TD, this sample was increased to include a minimum of ten from each grade. In order to ensure that adequate data were collected, 25 children were recruited in the CP subgroup.

3.3.3 Procedure

Approval was obtained from the Human Research Ethics Committee at the University of Cape Town (414/2006), the Department of Education^{vi} and heads of the three schools where the study was conducted. All learners with TD in Grades R (or reception or Gr. 0) to Grade seven who volunteered and who were selected by their class teacher from the school following a screening of the in- and exclusion criteria were

^{vi} Directorate for Education Research

invited to participate in the study. Similarly all learners with CP who were identified as meeting the inclusion criteria following screening by physiotherapists^{vii} from the school were invited to participate. Information leaflets and consent forms (Appendix 2) were sent home with the learners who volunteered to participate. Those learners who signed the assent form and whose parents signed the informed consent were finally included in the study.

3.3.3.1 Instrumentation

The following instruments were used to record data relating to demographics and abdominal muscle thickness measurements:

- A data collection sheet drawn up in Excel allowed for the recording of age, gender, diagnosis, grade, height, weight, BMI and thickness measurements for all four abdominal muscles.
- A Siemens® Accusonic X150 ultrasound imaging machine (Figure 1) with a 5.5cm wide band linear array frequency of 5Hz was used to capture B-mode (2-D) real-time images of the four abdominal muscles (refer to 2.6.3.2) . Conductive gel was used between the transducer and the skin.



Figure 1 Siemens® Accusonic X150 ultrasound imaging machine

^{vii} Registered physiotherapists working at the selected school - all are trained in neuro-developmental therapy (NDT)

- Height was measured using a standard tape measure attached to a wall. Without shoes, participants stood with their backs to the wall, asked to stand as upright as possible and height recorded using a metal ruler placed on the vertex of the skull parallel to the floor. In participants with CP who presented with a crouch stance, height was recorded only after their knees were passively extended and supported by an assistant.
- Weight was measured using a calibrated SALTER Personal Fitness Plus Scale (UK) (model 9191). Participants wore light clothing and were barefoot.
- BMI was calculated using the formula $\text{mass (kg)}/\text{height}^2 (\text{m}^2)$.

3.3.3.2 Location

An unused classroom was temporarily equipped with a plinth and used for the duration of the study at the two co-educational schools where children with TD were recruited. At the school where children with CP were selected for participation, a small private therapy room in the Physiotherapy Department was temporarily equipped with a plinth and used for the duration of the study. Participants were tested during school hours. Children from the same class accompanied each other during the testing sessions.

3.3.3.3 Testing procedure

Inter-tester reliability

For this part of the study the research assistants were four final year physiotherapy students who were trained to operate the ultrasound machine by the supplier and the primary researcher. They practiced together to familiarise themselves with the equipment and conducted a pilot study on ten children to ensure strict standardisation of the protocol to be used during the testing sessions. Two were trained to operate the transducer head, while the other two gave instructions to the child and applied resistance when indicated (refer to 3.3.3.4). The same child was tested twice on one day, first by the one tester (group) and an hour later by the second tester (group).

Intra-tester reliability

A similar procedure was followed for ten randomly selected participants from the same group of children with TD who were measured twice by the same tester on separate days (one to three days apart). In addition to these, 15 participants were tested twice on separate days, by the researcher taking measurement on her own.

Stability of abdominal muscle thickness in children with STCP (within day and between day test-retest reliability)

Both within-day and between day stability was investigated. The first session for within-day testing was conducted before interval and the second session after interval. For investigating stability over time, both sessions were conducted before interval a few days apart.

For this part of the study, the researcher captured all the images on her own. The procedure for capturing images and the activities participants were asked to perform for recording the contracted state of the four abdominal muscles were adjusted following lessons learnt from the recording of images in children with TD (refer to 3.3.8.1).

3.3.3.4 Capturing images

Capturing images in children with TD

Participants were positioned in supine with their arms resting along their sides on a plinth with their knees supported on a cushion, keeping their hips in $\pm 20-30^\circ$ of flexion (Figure 2). This ensured that participants were able to relax completely whilst maintaining the spine's neutral lumbar curvature.

A resting image was captured on end-inspiration as observed by the tester. Abdominal muscle activity during head-up and resisted sling activity was also investigated in children with TD. The second measurement therefore required a sub-maximal contraction by tucking in the chin and lifting the head (Figure 3). Participants were told to hold that position and the image captured. Following a one minute rest, a third image was recorded during an isometric sling activity (Figure 4), in which moderate resistance was applied by the second tester to the contra-lateral leg against hip flexion and adduction while the hip and knee were kept off the plinth in about $55 - 90^\circ$ of flexion. Resistance was given allowing a strong isometric contraction to be maintained. Following two minutes of rest, the process was repeated in order to capture resting and head up activity images for RA. Instead of resisted sling, resisted head up was performed by applying moderate resistance to the forehead at the end of the head lift eliciting a stronger isometric neck flexion contraction.



Figure 2 The supine position for the measurement of resting abdominal muscle thickness measurements



Figure 3 The head-up activity for abdominal muscle thickness measurements in a contracted state. Resistance was also applied to the forehead in the direction indicated (↘)



Figure 4 The sling activity (hip and knee flexion) for abdominal muscle thickness measurements in a contracted state. Resistance is applied above the knee in the direction indicated (↘)

For the TrA, OI and OE muscles, the transducer was positioned *initially* either three centimetres for children with a smaller body stature and/or trunk surface area or six centimetres for children with a larger body stature and/or trunk surface area, from the

midline in line with the umbilicus (*Position 1*) (Figure 5). The transducer was then moved further laterally until the medial edge of the TrA was approximately two centimetres away from the edge of the image as seen on the screen (Figure 7) when the participant was relaxed. This position was then marked on the participant's skin with a felt-tip pen to ensure that the transducer was kept in the same position for all of the measurements. Measurements were all taken on the left. For the RA the transducer was positioned approximately two centimetres above the umbilicus across the midline. The transducer position was then modified by moving one to two centimetres away from the midline (*Position 2*) (Figure 6) towards the left if necessary to ensure optimal image on the screen (Figure 9), then marked with a felt-tip pen. Marking the position of the transducer ensured that it was placed in the same position for recording during activity. The tester made every effort not to apply too much pressure through the transducer while testing.



Figure 5 *Position 1*: Position of the US transducer for capturing images of the TrA, OI and OE



Figure 6 *Position 2: Position of the US transducer for capturing images of the RA*

Inter-tester reliability The full procedure was repeated again by the second group of testers on the same day. Half of the children were tested by tester one first and the other half where tested by tester two first.

Intra-tester reliability The third measurement session was conducted two to four days later, on 23 learners (on ten by the research assistants and on 13 by researcher) randomly selected by drawing names from the first group of subjects from a hat. All images were stored on disc for later analysis.

Capturing images in children with CP

Participants were similarly positioned in supine with their arms resting along their sides on a plinth with their knees supported over a roller, keeping their hips in $\pm 20-45^\circ$ of flexion. This ensured that they were able to relax completely whilst maintaining the spine's neutral lumbar curvature as far as possible. Each participant was tested as follows:

A resting image of the three lateral abdominal muscles was captured on end-inspiration as observed by the tester with the transducer in *Position 1* as described above. The second measurement required a sub-maximal contraction by tucking in the chin and lifting the head. This activity was selected in order to apply sub-maximal resistance to the trunk stabilisers. Eliciting greater or maximal effort did not contribute to increased repeatability for this measurement in children with typical development (refer to 3.4.1)

as it caused more movement in the trunk, affecting the thickness measurement of the abdominal muscles. Participants were told to hold the position and the image captured. Following a one minute rest, a resting image for RA with the transducer in *Position 2* was captured at end-inspiration as well as for the head up activity also as described above. First the left side was measured and following a one minute rest the same procedure was followed to measure the right side. For within-day variability the second testing session was conducted in the afternoon and for between-day variability one to three days later.

3.3.4 Measurement and Data Processing

Machine cursors were used to measure muscle thickness in mm within the fascia boundaries. A similar procedure for thickness measurements as described by Ferreira et al. (2004)⁷⁸ was followed in the current study. The reference point was taken as the medial edge of the TrA and an imaginary line was drawn laterally. As the thickness of the muscle varies along the length of the muscle and in order to accommodate the natural curvature of the abdominal wall, three measurements were taken for TrA, OI and OE on lines at right angles to the imaginary line at 10mm, 15mm (Figure 7) and 20mm (Figure 8) from the medial edge of the TrA. The average of each of the three measurements was recorded for analysis.

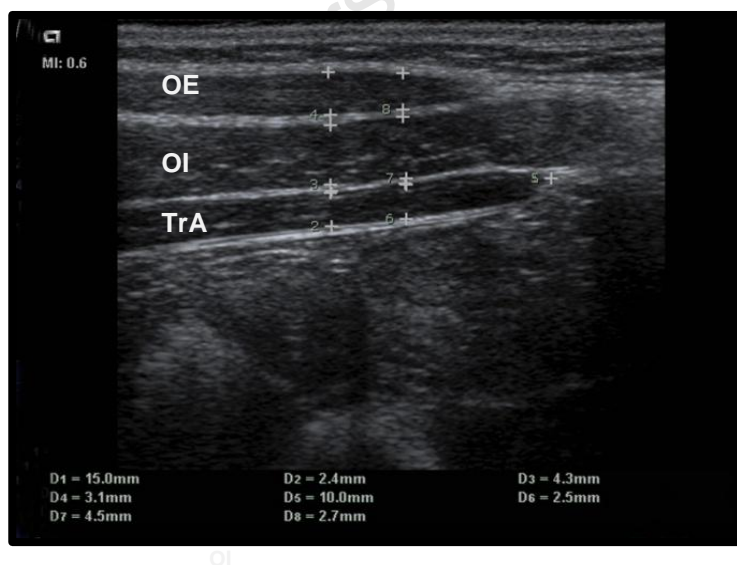


Figure 7 Cursor placements for measurement of TrA, OI and OE muscle thickness at 10mm and 15mm

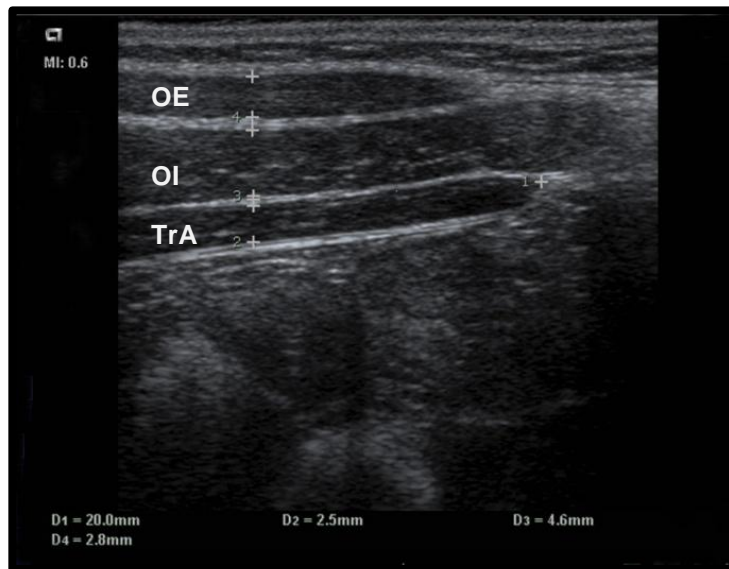


Figure 8 Cursor placements for measurement of TrA, OI and OE muscle thickness at 20mm

Similarly three measurements were taken for RA at 10mm, 15mm and 20mm from the medial border (Figure 9) and averaged.

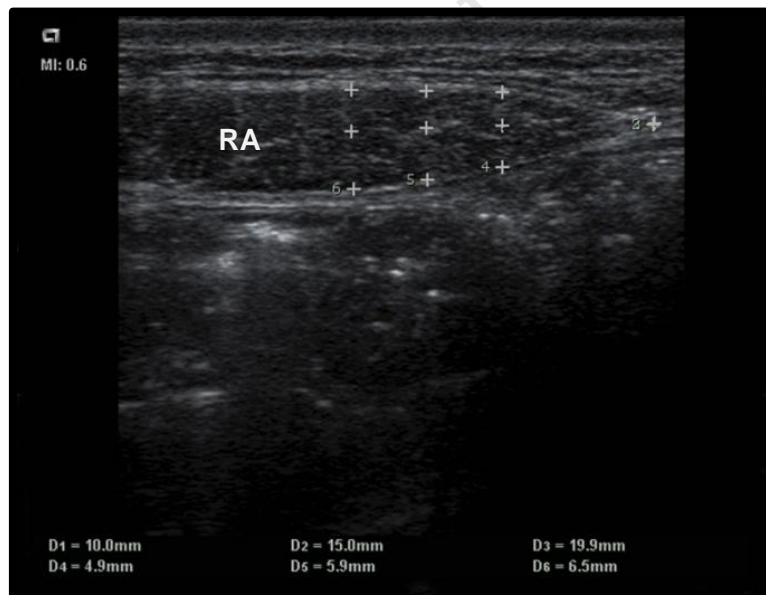


Figure 9 Cursor placements for measurement of RA muscle thickness at 10mm, 15mm and 20mm

3.3.5 Statistical analysis

The sample was described using descriptive statistics. According to Altman and Bland (2005) reporting of the standard deviation (SD) is a valid measure of variability regardless of the distribution of that variable within the sample³⁴³. However a different summary statistic, for example reporting the median and range is suggested when the 5% that fall outside the normal 2SD limits skews the distribution. As the sample size was relatively small, the distribution was tested for normality and the Kolmogorov-Smirnov test was used for this (Statistica).

3.3.5.1 *Inter- and intra-tester reliability: Pearson's Correlation vs. Intraclass Correlation Coefficient (ICC)*

There is discussion in the literature regarding the most appropriate analysis to use when investigating reliability of repeated measures. When comparison between two 'occasions' or two raters is conducted a correlation coefficient is typically calculated. The most widely-used type of correlation coefficient is the Pearson r (Pearson, 1896), also called a linear or product-moment correlation which determines the extent to which values of two variables or raters are "proportional" to each other (and are independent of the specific measurement units used) (Statistica). For comparison between raters, Pearson's r makes no assumption about rater means and therefore does not identify rater bias. A t -test will reveal if inter-rater means differ, provided that the sample size is adequate and the standard deviation is small. When sample sizes are small however Pearson's r may overestimate test-retest correlation.

Another widely used correlation coefficient is the Intra-class Correlation Coefficient (ICC). The ICC may be conceptualised as the ratio of between-groups variance to total variance and is sensitive to changes in both the order and the magnitude of repeated values (Statistica). There are several types of ICC's. ICC agreement for example compares each individual measurement and not just the group means whereas ICC consistency recognises/identifies consistency in measurement error^{344;345}.

In the current study ICC agreement - as opposed to consistency- using Statistica (version 8) was selected as the preferred means of analysis for the inter-tester and intra-tester studies in children with TD. Measurements within subjects are expected to vary somewhat due to the age, height and weight distribution of the current sample (six - 13yrs), compared with the means between the subjects. Furthermore the sample

sizes varied. As this study aimed to determine the reliability of measuring muscle thickness using US imaging, analysis of each measurement between testers (especially for the intra-tester study with the smaller sample size) was deemed appropriate in order to ensure rater bias or systematic error was identified.

Bland Altman plots were constructed to inspect systematic and random error of the test-retest data³⁴³ and values exceeding $>1.96 \times \text{SD}$ of the mean difference between the two testers for each muscle and activity were excluded from further analysis of those particular variables. This was done to ensure that potentially inaccurate measurements, which were clearly outliers, did not unduly influence the results. Variances between the two testers were estimated with a two-way, mixed effects model ANOVA³⁴⁶. ICCs and the standard error of measurement (SEM) were then calculated from these variance components. SEM is a theoretical standard deviation^{347;348} which estimates how much sample means will vary from the standard deviation (SD) where the SD is an estimate of the variability of the population from which the sample was drawn (Statistica). The SEM is defined as the root mean square of the within subject/rater variance $(\text{SD}/\sqrt{(\text{sample size})})$ ³⁴³. Furthermore the smallest real difference³⁴⁹ (SRD) was also calculated and computed as $1.96 \times \sqrt{2} \times \text{SEM}$. Beckerman et al. (2001) investigated and recommended the use of the SRD to assist in the interpretation and translation of correlational data in clinical trials and intervention practice in neuro-rehabilitation. Calculating the SRD was therefore deemed appropriate in order to establish effect size needed to suggest change in abdominal muscle thickness following intervention or monitoring progression over time.

Initially it was the intention to use the dependent t-test to detect a significant difference between the mean of the two testers, but, as the t-value increases as the SD of the measurement decreases, a significant t value might indicate a desirable low variance rather than an undesirable large difference between the values of the two sessions. Therefore, the following were identified *a priori* as criteria for reliability: an ICC value of more than 0.70 (ref) and/or a difference between the two scores of less than 7.5% of the mean of the first tester/measurement (ref).

3.3.5.2 Stability of abdominal thickness measurements in children with CP

Similarly intra-class correlation coefficient (ICC) using Statistica (Version 9) was also selected as the preferred means of analysis to test the stability of abdominal muscle

thickness across repeated measurements in children with STCP (within-day and between-day).

In order to allow for comparison between the left and right sides in subjects with hemiplegia the hemi side was recorded as the 'right side'. In other words in subjects with hemiplegia the affected side is being compared to the 'normal' or unaffected side, while in subjects with diplegia, the right side is compared to the left side.

3.3.5.3 *Gender differences and correlations between muscle thickness measurements and demographic characteristics*

As the sample sizes were relatively small, non-parametric statistics were used to test for relationships between variables. Mann-Whitney U tests were used to investigate differences in muscle thickness between male and females. The correlation between muscle thickness and age, height, weight and BMI was determined using Pearson's correlation if the value of the variables were normally distributed or Spearman's rank correlation if the values were not.

Standard multiple regression analysis was used to identify which variables were predictive of resting muscle thickness. A dummy variable was created for male/female and this, together with age, height, weight and BMI were entered. Diagnosis was also entered for children with CP with dummy variables created for hemiplegia/diplegia. Residual analysis was done and cases that were more than $1.96 \times \text{SD}$ away from the mean (outliers) were excluded from the final model. This was deemed appropriate as outliers (whether due to measurement error or exception to the norm – in this case group mean) may produce false predictors of resting thickness measures.

3.3.6 Ethical considerations

Approval was obtained from the relevant ethical review boards. Autonomy was ensured in that children volunteered to participate and participants were only recruited if written informed consent was obtained from their parent(s) or legal guardian. The participants were able to withdraw at any time, all data was processed anonymously and copies of the images captured were printed and given to the learners. All images that may be used in publication or presented at professional congresses and will be made anonymous by blurring of the faces. Measurements were taken with due regard to the

dignity of every individual in that adequate draping was insured and the location utilised allowed for privacy. As there were no known risks associated with any of the procedures conducted, the principle of non-maleficence was adhered to. No costs were incurred by participants. Inclusion of schools from both public and private sectors was deemed appropriate to ensure a wide spectrum of scholastic as well as socio-economic profiles thus ensuring a more representative sample. Although all learners from the CP population selected for participation came from traditionally disadvantaged backgrounds, the principle of justice was not violated as there were no known risks or benefits of taking part in the study.

3.4 Results

A description of the sample demographics, anthropometric measurements and a report of the findings regarding inter-tester and intra-tester reliability in children with TD is presented first as should the measurement not be found to be reliable, further analysis would be futile. This is followed by results pertaining to validity and the correlation analyses between muscle thickness and age, weight and height as well as whether characteristics such as gender, age and BMI are predictive of muscle thickness for each of the four abdominal muscles. This is followed by a description of the sample characteristics and stability findings in children with STCP. A description of what percentage difference between two measurements (a calculation based on the smallest real difference (SRD)) constitutes real difference when using US imaging to measurement abdominal muscle thickness will conclude this section.

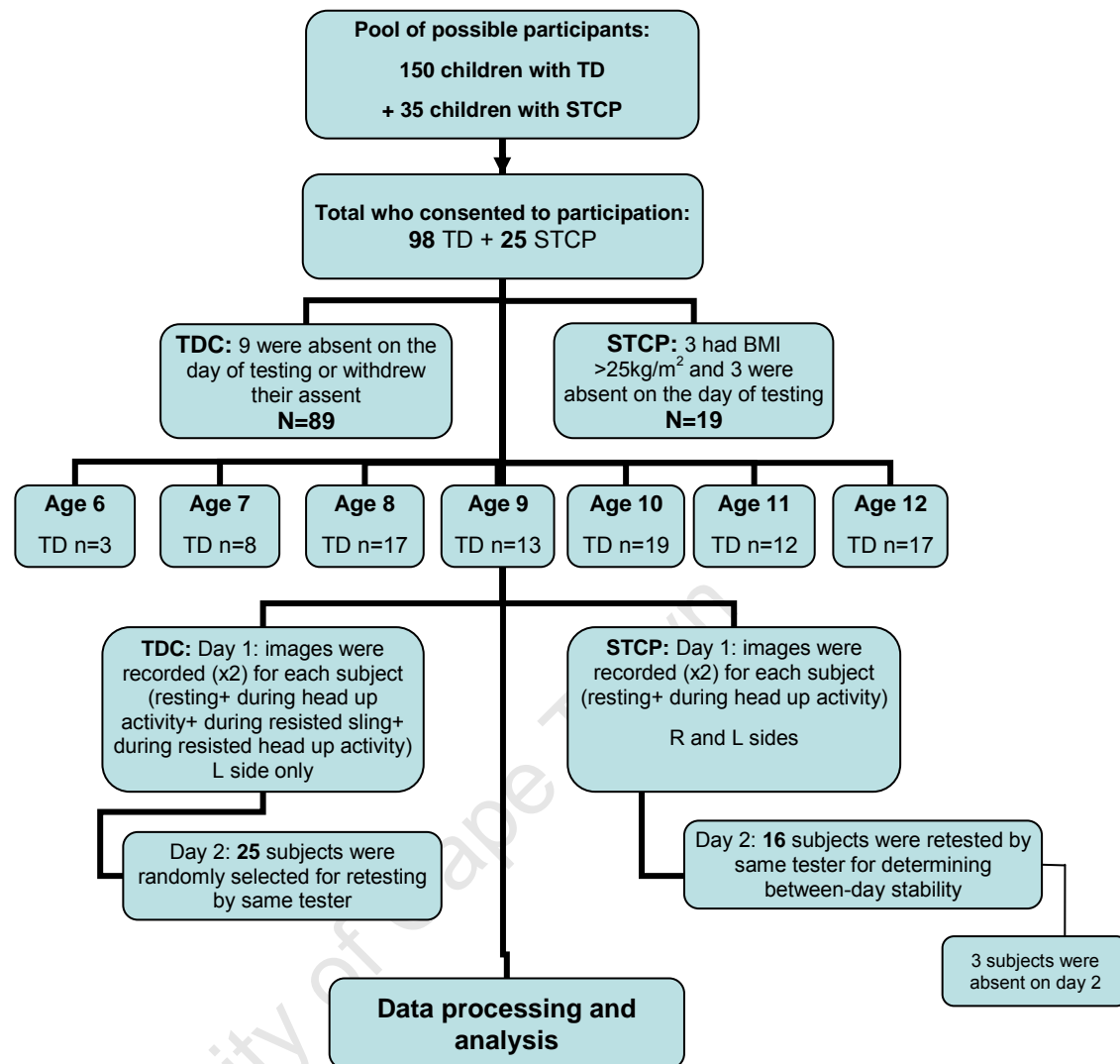


Figure 10 Participant recruitment and procedure

3.4.1 Ultrasound imaging in children with TD

3.4.1.1 Subject demographics and anthropometric measurements

Approximately 150 informed consent forms were handed out to learners at the two schools, 89 subjects were ultimately recruited to the study (Figure 10). There were 46 males and 43 females enrolled. The average height, body mass and BMI of participants in the current study can be seen in Table 1. None of the 89 subjects exceeded the $>25\text{kg/m}^2$ BMI value and none of the subjects presented with any neurological disorder or known disorder that may affect motor performance. Although

the Kolmogorov Smirnov test indicated that the data in all the variables were normally distributed, the range is also reported to indicate spread (Table 1).

Table 1 Subject characteristics (N=89)

Variable	Mean \pm SD	Range
Age in years	9.64 \pm 1.83	6-13
Height (cm)	142.9 \pm 13.5	121-176
Body mass (kg)	35.93 \pm 10.39	20-59.1
BMI (kg/m ²)	17.22 \pm 2.55	13.02-24.07

3.4.1.2 Inter-tester reliability

Table 2 lists the thickness measurements for all four abdominal muscles for both testers recorded on the same day, for resting as well as head up and resisted head up and sling activities. Not all the children were available for a second round of testing due to their respective school programs and two participants refused a second session. The data recorded for 64 children was ultimately used for analysis. Although 252 US images were captured for these 64 subjects (four each), approximately five percent of these were of poor quality and eliminated prior to analysis. The 'n' column in Table 2 is indicative of the final number of subjects (\cong no of images) ultimately included in the final analysis following further exclusion of those variables where the difference between the two testers exceeded $>1.96*SD$. In all cases less than seven were excluded except for the OI (Table 2). Why there were so many values that exceeded to $>2SD$ for this muscles is not clear.

All resting measurement met the *a priori* criteria for reliability, as did all measurements of the RA. However, the measurements of activity, including head up and resisted movements did not demonstrate reliability, with the exception of OI resisted sling (Table 2).

Table 2 Inter-tester comparison of abdominal muscle thickness measurements (in mm) for resting, head up, resisted head up and resisted sling activity in TDC (n=64)

Muscle	Activity	n (64)	Rater 1 mean±SD	Rater 2 mean±SD	diff. (mm)	SD diff	ICC (95%CI)	SEM	SRD	% diff./rater1
TrA	resting	58	2.44±0.61	2.49±0.66	-0.05	0.47	0.74 (0.60; 0.84)	0.32	1.39	2.0
OI	resting	58	4.76±1.70	4.74±1.67	0.01	0.87	0.88 (0.80; 0.93)	0.59	1.75	0.2
OE	resting	59	3.06±0.88	2.86±0.73	0.2	0.58	0.74 (0.57; 0.84)	0.39	0.72	6.5
RA	resting	59	4.79±1.04	4.71±1.10	0.07	0.76	0.83 (0.72; 0.89)	0.43	1.08	1.5
TrA	head up	59	2.75±0.74	2.92±0.87	-0.17	0.72	0.57 (0.30; 0.68)*	0.77	1.36	6.2
OI	head up	52	5.31±1.81	4.72±1.65	0.59	1.21	0.72 (0.50; 0.84)	0.87	2.22	11.1*
OE	head up	57	2.70±0.87	2.42±0.88	0.28	0.74	0.66 (0.42; 0.80)*	0.48	2.13	10.4*
RA	head up	56	7.07±2.30	7.50±1.99	-0.42	1.23	0.82 (0.70; 0.90)	0.87	3.74	5.9
RA	resisted head up	59	6.75±2.04	6.91±1.94	-0.16	1.21	0.81 (0.71; 0.89)	0.86	1.8	2.4
TrA	resisted sling	57	2.81±0.96	2.98±0.98	-0.17	0.79	0.45 (0.22; 0.63)*	1.13	1.39	6.0
OI	resisted sling	57	5.14±1.94	5.22±1.88	-0.08	1.17	0.84 (0.73; 0.90)	0.78	2.33	1.6
OE	resisted sling	59	2.93±1.12)	2.83±1.05	0.1	1.01	0.62 (0.44; 0.76)*	0.65	2.38	3.4

* *Criteria for reliability not met*

3.4.1.3 Intra-tester reliability

Table 3 lists the thickness measurements for all four abdominal muscles for Tester 1 recorded on two separate days. Two images were not included in the analysis due to absent data and the 'n' column is indicative of the final number of subjects (number of images) ultimately included in the final analysis following further exclusion of those variables where the difference between the two testers exceeded $>1.96*SD$. While the number of participants was 25, thickness measurements during resisted sling activity were not recorded in children from the private school and for this part of the analysis on nine subjects were included (Table 3).

Almost perfect agreement was found for all four resting abdominal muscles measurements with scores of 0.91 for TrA, 0.90 for OI, 0.91 for OE and 0.94 for RA. For the head up activity, OE's estimate for precision exceeded the 7.5% and is therefore not considered a reliable measurement while for TrA, OI and RA, thickness measurements during the head up activity all fulfilled all the criteria for reliability. For the resisted sling activities however, only the thickness measurement for OI could be considered reliable.

Table 3 Intra-tester comparison of abdominal muscle thickness measurements for resting, head up, resisted head up and resisted sling activity in TDC

Muscle	Activity	n (25)	Day 1 mean±SD	Day 2 mean±SD	diff. (mm)	SD diff	ICC(95%CI)	SEM	SRD	% diff. / day 1
TrA	resting	21	2.70±0.68	2.63±0.58	0.07	0.27	0.91 (0.79; 0.96)	0.19	0.53	2.59
OI	resting	22	4.93±1.45	4.83±1.35	0.10	0.63	0.90 (0.78; 0.96)	0.45	1.25	2.03
OE	resting	22	3.19±1.05	3.04±1.01	0.15	0.42	0.91 (0.79; 0.96)	0.30	0.83	4.70
RA	resting	23	5.39±1.34	5.56±1.33	-0.16	0.43	0.94 (0.87; 0.98)	0.30	0.83	2.97
TrA	head up	20	2.85±0.75	2.86±0.66	-0.01	0.35	0.88 (0.72; 0.95)	0.25	0.69	0.35
OI	head up	22	5.54±1.90	5.59±1.94	0.10	0.63	0.86 (0.68; 0.94)	0.74	2.05	1.79
OE	head up	20	2.59±0.91	2.87±1.04	-0.28	0.38	0.89 (0.61; 0.96)	0.27	0.75	10.81*
RA	head up	21	7.21±1.54	7.45±1.50	-0.24	1.16	0.71 (0.41; 0.87)	0.82	2.27	3.33
RA	resisted head up	9	7.11±2.06	7.60±2.37	-0.49	0.92	0.90 (0.63; 0.98)	0.65	2.38	6.89
TrA	resisted sling	9	2.81±0.80	3.02±0.77	-0.21	0.71	0.60 (-0.03; 0.89)*	0.5	3.13	7.47
OI	resisted sling	9	5.17±2.06	5.42±2.29	-0.26	1.19	0.86 (0.51; 0.97)	0.84	2.16	-5.03
OE	resisted sling	9	2.74±1.23	3.39±1.24	-0.65	1.22	0.49 (-0.07; 0.85)*	0.86	1.8	23.72*

* *Criteria for reliability not met*

3.4.1.4 Discriminative validity

As the analysis for tester reliability in children with TD shows that muscle thickness as measured during real-time ultrasound imaging during rest is reliable, further analysis using the first measured resting data recorded by Tester 1 was then performed.

An independent t-test was done in order to determine whether there was a significant difference between the resting and head up activities for the sample (Table 4). For all

four abdominal muscles there was a significant difference between resting and head up thickness measurements, with RA showing the greatest increase. Apart for OE the value increased from resting to head up. The OE value decreased.

Table 4 T-test for detection of difference between resting and head up activity in TDC (n=89)

	Mean	SD	N	diff.	SD diff.	t	df	p
Resting TrA (mm)	2.59	0.67						
Head up TrA (mm)	2.83	0.95	85	0.24	0.82	2.72	84	<0.008*
Resting OI (mm)	5.02	1.58						
Head up OI (mm)	5.64	2.02	87	0.62	1.01	5.71	86	<0.001*
Resting OE (mm)	3.20	0.93						
**Head up OE (mm)	2.82	0.95	85	-0.37	0.68	-5.12	84	<0.001*
Resting RA (mm)	5.19	1.26						
Head up RA (mm)	7.28	1.91	88	2.09	1.49	13.23	87	<0.001*

*p<0.001

**This analysis is flawed in that OE was not found to be reliable and should be interpreted with caution.

3.4.1.5 Convergent validity

Table 5 confirms the assumption that older children with TD have thicker muscles. Similarly taller and heavier children present with thicker abdominal musculature.

Age For children with TD a significant correlation existed between age and resting abdominal muscle thickness measurements (Table 5).

Height, weight and body mass index Similarly a similar significant correlation existed for height, weight and BMI and resting abdominal muscle thickness measurements with p<0.001 for all measurements (Table 5).

Table 5 Correlation between resting muscle thickness and age, height, weight and BMI (Pearson's r)

	age	height	weight	BMI
Muscle	r	r	r	r
TrA	0.36	0.37	0.52	0.54
OI	0.55	0.60	0.65	0.50
OE	0.57	0.60	0.64	0.50
RA	0.51	0.57	0.56	0.40

p<0.001 in all cases

Standard multiple regression analysis was conducted in order to determine which variables (age, gender and/or BMI) predict resting muscle thickness in children with TD. These analyses resulted in models which explained from 27% (RA) to 47% (OE) of the variance. Different variables were found to be predictive of the thickness of the different muscles. Age was a significant predictor in all four abdominal muscles, with older children demonstrating thicker muscles. Females had a predicted reduced thickness in OI and OE and increased BMI was found to be a significant predictor of increased TrA, OI and OE resting muscle thickness (Table 6).

Table 6 Regression summaries of variables predictive of resting muscle thickness in children with TD

resting TrA (4)*	b		SE - of b	t(81)	p	Adjusted R ²
	Intercept	9.29	10.14	0.92	0.362	0.39
	Gender	-0.09	0.10	-0.93	0.355	
	Age	0.06	0.03	2.06	0.043	
	BMI	0.12	0.02	5.40	0.000	
resting OI (1)*	b		SE - of b	t(83)	p	Adjusted R ²
	Intercept	94.3	24.866	3.79	0.000	0.43
	Gender	-0.94	0.245	-3.8	0.000	
	Age	0.38	0.075	5.01	0.000	
	BMI	0.15	0.055	2.73	0.008	
resting OE (5)*	b		SE - of b	t(79)	p	Adjusted R ²
	Intercept	40.28	14.01	2.88	0.005	0.47
	Gender	-0.41	0.14	-2.93	0.004	
	Age	0.16	0.04	3.62	0.001	
	BMI	0.14	0.03	4.57	0.000	
resting RA (4)*	b		SE - of b	t(81)	p	Adjusted R ²
	Intercept	13.64	20.29		0.503	0.27
	Gender	-0.12	0.20	-0.60	0.549	
	Age	0.27	0.06	4.46	0.000	
	BMI	0.06	0.04	1.34	0.183	

* Number of outliers eliminated

3.4.2 Ultrasound imaging in children with STCP

3.4.2.1 Subject demographics and anthropometric measurements

Thirty five informed consent forms were handed out to learners at the school. Twenty five subjects agreed to participate and their parents signed the informed consent forms (Figure 10). A further two children were later excluded as their BMI values exceeded 25kg/m² and another three were absent on the day of testing. Of the final 19 subjects (nine children with hemiplegic and ten children with diplegic spastic type CP) enrolled in the current study, eleven were male and eight were female, six subjects in GMFCS Level I, eleven in Level II and two in Level III. The average height, body mass and BMI of participants in the current study can be seen in Table 7.

Table 7 Subject characteristics (N=19)

Variable	Mean	SD	Range
Age (years)	10.63	1.42	8 - 12
Height (cm)	138.47	9.5	120 - 157.5
Body mass (kg)	29.77	5.4	18.7 - 39.3
BMI (kg/m ²)	15.49	2.1	12.98 - 19.98

3.4.2.2 *Within-day stability of abdominal muscle thickness measurements*

In total 152 US images were captured for 19 subjects (eight each, four on the left and four on the right) at the first testing session. Of these 17 subjects were retested on the same day after their interval. The two eight year olds were unavailable for retesting as the junior school had already left for home on that day.

The images of two subjects at the second testing session were of poor quality and had to be eliminated prior to analysis for this part of the study. The maximum number of outliers excluded was three. Table 6 lists the thickness measurements for all four abdominal muscles for both test sessions recorded on the same day, for resting as well as during the head up activity. All resting as well as head up activity measurement met the *a priori* criteria set for reliability (Table 8).

Table 8 Within-day comparisons of L and R abdominal muscle thickness measurements during resting and head up activity for all four abdominal muscles in STCP

Muscle		Activity	Measure 1 mean±SD(mm)	Measure 2 mean±SD(mm)	n (15)	ICC (95%CI)	diff. (mm)	SD diff.	% Diff./ measure ment1	SEM	SRD
Left*	TrA	resting	2.74±0.50	2.64±0.47	14	0.89(0.66;0.96)	0.10	0.23	3.65	0.16	0.22
	OI	resting	6.46±1.71	6.19±1.33	14	0.88(0.68;0.96)	0.27	0.73	4.18	0.51	0.69
	OE	resting	3.84±0.87	3.92±0.76	13	0.74(0.33;0.91)	-0.08	0.60	-2.08	0.43	0.58
	RA	resting	5.85±1.09	5.74±1.37	14	0.89(0.69;0.96)	0.10	0.60	1.71	0.42	0.57
	TrA	head up	2.62±0.55	2.74±0.60	14	0.76(0.41;0.91)	-0.12	0.40	-4.58	0.28	0.38
	OI	head up	6.39±1.43	6.08±1.57	14	0.85(0.61;0.95)	0.30	0.79	4.69	0.56	0.76
	OE	head up	3.59±0.90	3.83±0.72	14	0.71(0.33;0.90)	0.20	0.61	5.57	0.43	0.58
	RA	head up	8.63±1.49	8.36±1.92	13	0.87(0.65;0.96)	0.28	0.86	3.24	0.61	0.83
Right**	TrA	resting	2.42±0.53	2.48±0.52	14	0.95(0.41;0.91)	-0.06	0.16	-2.48	0.12	0.16
	OI	resting	6.68±1.68	6.70±1.18	14	0.85(0.60;0.95)	-0.02	0.82	-0.30	0.58	0.79
	OE	resting	3.83±1.12	4.02±0.84	13	0.89(0.68;0.96)	-0.18	0.45	-4.70	0.32	0.43
	RA	resting	6.10±0.81	6.10±0.97	12	0.96(0.86;0.99)	0.04	0.27	0.66	0.19	0.26
	TrA	head up	2.53±0.51	2.53±0.52	15	0.83(0.56;0.94)	-0.00	0.31	0.00	0.22	0.30
	OI	head up	6.80±1.59	6.63±0.93	14	0.80(0.49;0.93)	0.17	0.93	2.50	0.66	0.90
	OE	head up	3.60±1.02	3.70±0.82	12	0.86(0.60;0.96)	-0.10	0.49	-2.78	0.35	0.48
	RA	head up	8.00±1.48	8.30±1.63	12	0.87(0.61;0.96)	-0.30	0.79	-3.75	0.56	0.76

* Less affected side ** more affected side in children with hemiplegia

3.4.2.3 Between-day stability of abdominal muscles thickness measurements

Sixteen subjects were available for the third testing session but the images of one subject were eliminated due to poor quality. Table 9 lists the thickness measurements for all four abdominal muscles recorded on the two separate days, for resting as well as during head up activities. All resting as well as head up activity measurement for TrA and RA met the *a priori* criteria for reliability. Not all criteria for the head up activity for the OI and OE muscle were met on the right side (Table 9). The ICC was .68 for OI head up and the difference in the OE from one occasion to the next was 9%.

Table 9 Between-day comparisons of L and R abdominal muscle thickness measurements during resting and head up activity for all four abdominal muscles in STCP (n=15)

Muscle		Activity	Measure 1 mean±SD(mm)	Measure 2 mean±SD(mm)	n (15)	ICC (95%CI)	diff. (mm)	SD diff.	% Diff. / measure 1	SEM	SRD
Left	TrA	resting	2.82±0.47	2.68±0.36	13	0.81(0.45;0.94)	0.14	0.23	4.96	0.17	0.23
	OI	resting	6.36±1.74	6.54±1.49	13	0.92(0.76;0.97)	-0.18	0.67	-2.83	0.47	0.64
	OE	resting	3.96±0.98	4.09±0.82	12	0.91(0.72;0.97)	-0.14	0.38	-3.54	0.27	0.37
	RA	resting	5.66±1.03	5.68±1.07	12	0.98(0.93;0.99)	-0.03	0.21	-0.53	0.15	0.20
	TrA	head up	2.72±0.57	2.58±0.46	13	0.77(0.41;0.92)	0.14	0.34	5.15	0.24	0.33
	OI	head up	6.45±1.62	5.97±1.99	13	0.88(0.61;0.97)	0.48	0.78	7.44	0.55	0.75
	OE	head up	3.44±0.96	3.56±1.09	13	0.91(0.73;0.97)	-0.12	0.45	-3.49	0.32	0.43
	RA	head up	8.49±1.34	8.44±1.65	12	0.82(0.49;0.95)	0.05	0.92	0.59	0.65	0.88
Right	TrA	resting	2.39±0.57	2.39±0.52	12	0.93(0.78;0.98)	-0.01	0.21	-0.42	0.15	0.20
	OI	resting	6.44±1.69	6.30±1.36	14	0.89(0.71;0.96)	0.14	0.72	2.17	0.51	0.69
	OE	resting	3.89±1.15	3.83±0.97	12	0.95(0.84;0.99)	0.06	0.34	1.54	0.24	0.33
	RA	resting	6.11±0.82	5.88±1.03	13	0.76(0.40;0.92)	0.23	0.63	3.76	0.45	0.61
	TrA	head up	2.53±0.53	2.42±0.60	14	0.73(0.37;0.91)	0.11	0.41	4.35	0.29	0.39
	OI	head up	6.69±1.64	6.92±1.54	14	0.68(0.25;0.88)*	-0.23	1.30	-3.44	0.92	1.25
	OE	head up	3.60±1.02	3.92±0.97	12	0.85(0.48;0.96)	-0.32	0.47	-8.89*	0.33	0.45
	RA	head up	8.30±1.57	8.35±1.55	14	0.85(0.60;0.95)	-0.04	0.87	-0.48	0.62	0.84

* Less affected side ** more affected side in children with hemiplegia

3.4.3 Calculation of the smallest real difference (SRD)

The minimum difference required between repeated measurements to indicate real difference or change was calculated for within-day and between day measurements.

The percentage difference between repeated measures for each muscle was calculated as SRD/measurement 1*100. These values are presented in Tables 10 and 11 for children with TD and children with CP respectively.

Table 10 Interpretation of the SRD in children with TD

Muscle	Activity	% change for different raters	% change for between-day measurements(same rater)
TrA	resting	57%	20%
OI	resting	37%	25%
OE	resting	24%	26%
RA	resting	23%	15%
TrA	head up	49%	24%
OI	head up	42%	37%
OE	head up	79%	29%
RA	head up	53%	31%
RA	resisted head up	27%	33%
TrA	resisted sling	49%	112%
OI	resisted sling	45%	42%
OE	resisted sling	81%	66%

'%' ≈ measurement did not meet criteria for reliability (refer to Tables 8 and 9)

The percentage change required for detection of real difference between repeated measurements was also calculated for within-day and between day-measurements in children with STCP (Table 11).

Table 11 Interpretation of the SRD in children with STCP

Muscle		Activity	% change for within-day measurements	%change for between-day measurements
Left	TrA	resting	8%	8%
	OI	resting	11%	10%
	OE	resting	15%	9%
	RA	resting	10%	4%
	TrA	head up	1%	12%
	OI	head up	12%	12%
	OE	head up	16%	13%
	RA	head up	10%	10%
Right	TrA	resting	7%	8%
	OI	resting	12%	11%
	OE	resting	11%	8%
	RA	resting	4%	10%
	TrA	head up	12%	15%
	OI	head up	13%	19%
	OE	head up	13%	13%
	RA	head up	10%	10%

'%' ≈ measurement did not meet criteria for reliability (refer to Tables 8 and 9)

3.4.4 Summary of results

Reliability In children with TD the ICC scores met the criteria for inter- as well as for intra-tester reliability for all four abdominal muscles under passive conditions. Reliability for the measurement of muscle thickness during sub maximal active conditions (head up) for RA muscle was also found.

Discriminative validity US imaging can discriminate between active and passive conditions in all four abdominal muscles in that significant difference was found in thickness measurements between the passive and active states.

Convergent validity If it is assumed age and height (and BMI) is related to muscle thickness, then convergent validity was proven in children with TD for these constructs.

Stability of abdominal muscle thickness measurements in children with STCP

The ICC scores met all the criteria for stability within-day and between-day for all four

abdominal muscles during rest conditions. Similarly the criteria for stability of abdominal muscle thickness during contracted conditions were met for all four muscles for within-day repeated attempts.

The smallest real difference In children with TD, in order to consider two thickness measurements of the same abdominal muscle different from one another, the percentage difference between the two measurements must be higher when taken on the same day (where values ranged between 25.5% and 57%) when compared to the difference required when measurements are taken on different days (where values ranged from 15.4% and 41.8%). In children with STCP however the difference between repeated measurements is much lower with values ranging between 4.3% and 16.2% for within-day measurements, while a similar difference or change (3.5% to 15.4%) is required for between-day measurements.

3.5 Discussion

Results from the current study suggest that two dimensional ultrasound imaging is a valid and reliable method for measuring the thickness of the four abdominal muscles, namely transversus abdominis, obliquus internus and externus and rectus abdominis in children, under resting and some active conditions. The measurement also demonstrated convergent validity in children with TD in that they showed that age and BMI were correlated with thickness in most muscle groups. In addition US imaging was able to discriminate between resting and active contraction in children with TD in all cases. This study has also provided evidence for stability of resting abdominal muscle thickness measurements over time (both within-day and between days) in children with spastic type cerebral palsy. This section will also discuss in more detail the results pertaining to demographic characteristics of the sample, and their representativeness as well as the potential utility of ultrasound imaging for description of and investigating abdominal muscle activity in children with pathology.

3.5.1 Tester reliability for resting abdominal muscle thickness

All the criteria for both inter- and intra-tester reliability set at the onset of the study were met for measuring resting abdominal muscle thickness in children with TD suggesting

that ultrasound is a reliable instrument this purpose. With ICCs of above .87 intra-tester within-day and between day reliability coefficients for resting TrA, OI and OE muscle thickness were similar to those reported for adults^{78;320;326;328}. In the current study analysis of inter-tester reliability showed lower ICC scores ($r < .90$) than for intra-tester reliability ($r > .90$) for measuring the resting thickness of the four abdominal muscles. Hides et al. (2007) highlights that the experience of the tester affects reliability of repeated measurements³²⁶ and as the testers in the current study were undergraduate physiotherapy students who only had a week to master the technique, slightly lower scores were expected. Although guidelines for optimal positioning exist, the placement of the ultrasound transducer is manipulated by the tester to ensure the correct image on the screen as the thickness of the abdominal muscles is not consistent along its lengths. This may also account for the difference in actual measurement for each subject between the two testers in some cases.

Elimination of outliers was considered appropriate in the current study due to the relative inexperience of the research assistants. The images of approximately 6% of subjects were eliminated due to poor quality of the image. It is not clear why this occurred. Another 1 - 13% of images were eliminated during inter-tester analysis as they exceeded the 2SD criterion, while 0 – 20% were eliminated during the intra-tester analysis. These numbers are high and do raise questions regarding either the validity of the instrument or, more likely, inexperience significantly affected accuracy.

3.5.2 Discriminant validity and responsiveness

Although the validity of thickness measures using US imaging as indicator of abdominal muscle activity was not determined in the current study, as would be expected for a valid measure, US imaging was found to be adequately responsive in terms of detecting change and recording a difference in thickness between resting and activity within children with TD. Considerable variation in muscle thickness during the supine positioned head up and resisted activities was seen for TrA, OI and OE and RA muscles in the current study. This was especially so for the OI thickness measurement during the head up activity where three images were eliminated due to absent data, the rest of the images – another eight – were eliminated prior to the analysis of this variable due to differences between the two testers exceeding $>2SD$'s (Table 2). This rendered low ICC scores of this measurement for inter-tester reliability. Although the

difference between the two testers was much smaller for the resisted sling activity, the variability of the thickness of this muscle resulted in unacceptably low ICC values for TrA and OE. The ICC score for OI however was considered reliable. The lesser variability displayed during the resisted sling activity for the OI muscle could be attributed to the fact that during this activity strong to maximal resistance was applied by the tester eliciting a strong rotational force on the spine and therefore due to the nature of the external force, the contra-lateral obliquus internus muscle was specifically targeted²⁶⁵.

Reliability of a measurement requires stability of the attribute being measured. This study has demonstrated US imaging to be reliable for the measurement of resting thickness and t-tests comparing resting to activity thickness measurements suggest that US imaging is a valid tool, adequately responsive in detecting change following activity. The variation in thickness measurements and lower correlations between inter-tester scores observed during activity therefore suggests that children might recruit abdominal muscle to stabilise the spine during head and lower limb activity in inconsistent patterns. Furthermore variation exists between individuals. EMG studies in the adult population have also found this variation to exist among individuals^{310;350}. The low percentage change between resting and the head up and resisted sling activities also suggests poor recruitment of the stabilising TrA and OI muscles for these activities as compared to adults⁷⁸.

3.5.3 Convergent validity

As it may be assumed that older children will have larger (thicker) abdominal muscles, the relationship between age, height, weight and body mass index were investigated in children with TD. Findings in the current study show that resting thickness measurements in children six to thirteen years of age are smaller than those reported in the adult population^{77;323;341;351}. Rankin et al.'s (2006) described the resting thickness of the TrA, OI and OE muscles in 123 adults across the lifespan. The men were significantly older, taller and heavier and had greater BMI's than women, whereas in the current study these variables did not differ significantly between the boys and the girls (refer to Chapter 4). The significant difference in body mass accounted for the significant difference found in muscles thickness between adult men and woman. No correlation was found in adults between resting muscle thickness for any of the

abdominal muscles and age, height or BMI in Rankin et al.'s sample of adults³⁵¹. In contrast significant correlation was found between age and resting thickness for all four muscles in the current sample of six to 13 year old children as well as for height, weight and BMI. The assumption that older, heavier and or taller children have thicker abdominal musculature than their younger, shorter and or thinner counterparts appears to be likely. This is borne out by the regression analysis which indicated that age and BMI were dependent predictors of the thickness of most abdominal muscles.

3.5.4 Stability of muscle thickness measurements in children with STCP

In the current study, stability of muscle thickness measurements was further investigated in children with spastic type cerebral palsy. In the supine position the thickness recorded at rest remained stable for both within-day and between days with ICC scores ranging between 0.71 and 0.96. Stability was also found for all of the muscles during the head lift activity for both sessions, except for the OI muscle during the head up activity measured between-days. When compared to children with TD, the ICC scores for resting thickness demonstrate greater stability in the CP group for the within-day measurements. Similar scores were however found for both groups at the between-day recordings. These results suggest greater stability to exist within-day in resting thickness of the abdominal muscles in children with STCP compared to children with TD. For the head up activity for both within-day and between-day, the CP group demonstrated greater stability than when compared to the group with TD. It is hypothesised that spasticity occurs in the trunk musculature in children with STCP and that the increased co-contraction results in a more rigid spinal column¹⁷⁸. Increased tone and spinal rigidity may account for greater lumbo-pelvic stability which produced a more consistent pattern of recruitment of the abdominal muscles during the fully supported supine position while the head is being lifted. Hadders-Algra's (2000) explains in her neuronal group selection theory why this decrease in variability of movement is commonly seen in children with CP²⁰ and was therefore not unexpected.

3.5.5 Pattern of abdominal muscle recruitment during head up and resisted sling activity

Although variation within individuals in recruitment of the abdominal muscles during repeated upper and lower limb activities has been reported in the adult literature^{310;350}, using repeated thickness measurements during contraction may not have been indicated for determining reliability of ultrasound imaging. However as this is a novel approach to investigating abdominal muscle activity in children, head up and resisted sling activities were also investigated in children with TD.

ICC's for intra-tester and within-day reliability for the head up activity showed higher and by definition more reliable scores than for inter-tester and between day measurements. The thickness measurement however for the OE muscle did not comply with the *a priori* criteria as the percentage difference between the means of the two readings exceeded the 7.5% threshold. For the OE muscle the mean thickness measurement in the contracted state was lower than the resting mean suggesting that the muscle was either stretched or compressed by the other abdominal muscles during the head up activity. Whether there was any activity in this muscle is unknown and would have to be verified with EMG.

There was greater variance between the two measurements in the abdominal muscles during the resisted sling activity. Unfortunately due to an error in planning no image was recorded for the RA muscle under these circumstances. The thickness measurement for the OI muscle did comply with all the criteria for reliability for this activity. These results were also seen in the values recorded for this measurement between testers (inter-tester reliability analysis). The more consistent measurement for the OI muscles may be explained in that unilateral limb activity primarily elicits activity in the contra-lateral OI muscle. The different values recorded for the TrA muscle with repeated attempts furthermore suggest inconsistency in recruitment of this muscle in providing stability to the lumbar spine and pelvis during this activity.

It is suggested that the variation seen in recruitment pattern from one session to the next may be a major contributor to the unacceptably low ICC intra-tester scores for this activity for TrA and OE muscles, rather than simply measurement error. On the other hand, difficulty in correct placement of the transducer during contractions might be another factor and this was evidenced by the greater number of poor quality images generated during active when compared to resting conditions.

There was great variation within the performance of the head up and sling activity in the group of children with TD and it was noticed that the muscle thickness of the three lateral abdominal muscles, TrA, OI and OE often decreased while all subjects showed an increase in thickness of the RA during these activities. The role of the abdominal muscles during these activities is to stabilise the trunk and this thinning of the lateral abdominal muscles may suggest that these children are predominantly using the RA muscle to stabilise the spine and are not yet sufficiently recruiting the stabilising function of OI and TrA as has been demonstrated in the healthy adult population^{24;70;78;108;352}. Thinning of these muscles during the activity also suggest that these muscles are being stretched possibly as the chest wall is being pulled down by the shortening/contracting/thickening RA. Some of the subjects however were able to recruit especially the OI and to a lesser extent TrA to stabilise the spine. Anecdotal observational movement analysis also suggests that quality and range of movement was better in these subjects. Investigation into the relationship between range of movement (or quality) and pattern of recruitment in the abdominal muscles is recommended to further explain the difference noted between repeated attempts.

The head up activity could be considered a sub maximal or low intensity activity for recruiting the abdominal stabilisers, whereas the resisted activities – the resisted head up and sling activities - could be considered maximal or high intensity activity. For the head up activity, the subjects were instructed to tuck in the chin and lift the head onto the chest and it was observed that movement patterns such as speed with which the head was lifted, the height lifted from the plinth and associated upper limb activity such as pushing into the plinth varied across repeated attempts. Similarly a wide variety of strategies were implemented for the resisted sling activity. If comparison is going to be made between subjects for recruitment of these muscles standardisation of the activity needs to be ensured³¹¹. This seems to be supported by the current study where in the TD group the resisted head up activity resulted in higher ICC scores for RA than for the same activity without resistance (Table 3). Although there is some debate in the literature regarding the *responsiveness* of the ultrasound abdominal muscle thickness measurements to varying levels of activity intensity^{80;320}, standardising the resistance offered by the tester may contribute to less variation in performance across attempts which may result in a more repeatable measurement.

Ferreira et al. (2004)⁷⁸ and Hodges et al. (2003)⁸⁰ reported that changes in abdominal muscle thickness measurements correlate highly with electromyography (EMG)

recordings of muscle activity. Studies show there to be a curvi-linear relationship between level of activity and change in muscle thickness and for contraction below 30% of the maximal voluntary contraction (MVC) this relationship is linear³⁵³. Correlation of EMG recorded muscle activity with abdominal muscle thickness measurements in children however still need to be done in order to determine if US measured abdominal thickness is a valid tool for investigating motor control strategies utilised by children. The relationship between various movement parameters and changes in muscle thickness also still need to be explored.

3.5.6 Feasibility of US imaging in children

It is essential that physiotherapists can use US imaging for investigating the abdominal muscles in children reliably if it is to be used as a clinical outcome measure and to monitor change during intervention. The data collection was performed by researchers (physiotherapy students) who were unfamiliar with the technique but who received one week's training prior to implementation. The results suggest that physiotherapists can reliably use US imaging. ICC scores in the current study were slightly lower than those reported in the literature for studies conducted in the adult population. Researchers such as Richardson, Hodges and Ferreira are considered expert in their field with years of experience in measurement and interpretation of abdominal muscle activity and this may account for the increased reliability in their studies.

Although the financial outlay for an ultrasound machine is considerable, the only consumable expense is the conductive gel and tissue paper/towels. This method is deemed safe in that the levels of radiation are negligible for humans and the technique does not involve any invasive procedures which would increase the risk for infection. The unit is easily transportable and can be used within any environment such as schools, clinics etc. None of the children objected to testing, despite the novelty thereof. The testing procedure is quick, exposure of the lower abdomen required no undressing and although some of the children were rather sensitive to touch, they were eventually able to relax completely for the capturing of the resting images. A printout of one of the images captured allowed for the opportunity to educate them regarding their abdominal anatomy.

3.5.7 Clinical relevance of muscle thickness measurements

The current study provides evidence that US imaging is a valid instrument for the measurement of abdominal muscle thickness. Differences were noted between children with TD and children with CP and were further investigated in the next study (Chapter 4). The order of relative thickness of the four muscles differed between the two groups of children with RA>OI>OE>TrA in children with TD, while in children with CP OI was thicker than the RA. Although the reasons for these differences at this stage are largely speculative, accurate measurement of these differences and developing an understanding of this will contribute to improved treatment and therapeutic approaches in children with motor dysfunction.

When monitoring a patient or when investigating the efficacy of an intervention, the repeatability of the measurement is important to ensure that even a slight change can be detected. The SEM is an indication of the precision of the measurement and estimates how much the sample means deviate from the standard deviation³⁴³ and should therefore be taken into account when interpreting correlation coefficients. The smaller the SEM, the more accurate / repeatable the measurement can be considered. In the current study the SEM values were relatively small suggesting that, whether there may or may not have been agreement between or within testers, there was little uncertainty about the estimate of the mean and that the testers were fairly precise in their measurements.

The calculation of the SRD from the SEM is clinically valuable when the responsiveness to change is important as the SRD is an indication of how much change must occur in order to consider the effect of the intervention or change of status as change due to intervention and not due to measurement error. A wide range of SRD values was found in the current study. These ranged from 0.53mm for resting TrA muscle thickness measurements to >3mm for some of the head up and resisted sling activities (Tables 2 and 3). This implies that for an intervention to be regarded as having an impact the resting thickness measurement of the TrA muscle, for example, must exceed 0.53mm (or increase by 19.6%). It could also be argued that from these varied - and for some muscles large - percentage change required implying difference between the two measures, that US imaging is not responsive enough to detect smaller changes in this relatively thin muscle group. The relationship between measurements of muscle thickness and muscle strength however still need to be determined.

The percentage change required to represent real change in children with STCP was lower than those recorded for children with TD again suggesting greater stability of this measurement using ultrasound imaging across time within this population.

Results from the current study suggest that resting abdominal muscle thickness measurements using US imaging are responsive and reliable for the detection of change. The varied, less repeatable outcome of the change in thickness during activity, especially maximal resisted activity suggests that recruitment patterns differ across attempts in children with TD. This coupled with more difficult placement of the transducer head which leads to poorer images, may have reduced the reliability of the measure in active contracting muscles. This needs further investigation.

3.6 Limitations of study

The following limitations were identified:

- Capturing US images was conducted by students as well as an experienced NDT therapist. All are novices in ultrasonography. Although the results show repeatability and relative stability of the measurement of abdominal muscle thickness, placement of the transducer and pressure exerted on the skin is subjective and may have produced errors as was observed by the differences recorded for the ICC scores between left and right sides.
- Without EMG verification only assumptions relating to muscle activity can be made – however in the absence of ethical approval for invasive techniques in children, hypotheses generated by these studies can only be based on theory.
- In light of the above, the responsiveness of the thickness measurements is questionable, particularly when measuring thickness during contracted state. There is discrepancy in the adult literature concerning the relationship between US and muscle activity, similarly it is assumed that this will also be true regarding the relationship between change in thickness and motor performance in children. Whether US imaging is a valid measure of muscle activity especially in children remains as yet unknown.
- Only the left side was recorded in this group of children. Left or right sided dominance may have resulted in asymmetry, but this was not explored in the current study.

- Outliers – measurements which did not fall within the 95% confidence interval – were eliminated in the current study. As no normative values for children with TD exist for comparison these outlier values were presumed to be true outliers and therefore excluded. However should their values fall within ranges for children with TD, these data should have been included in the analysis as children classified as GMFCS Level I were included in this study. By definition children with CP in level I closely resemble children with TD in terms of functional ability. Alternatively the relatively small sample size and purposive sampling method (school selection) may have resulted in an under represented range of children with CP within these three functional levels.
- Although the current sample size was deemed appropriate for statistical analysis, the variation in clinical presentation of the children with STCP demanded further investigation into the various factors contributing to motor dysfunction. The sample size for the group with CP was too small to allow for sub-group analysis.

3.7 Recommendations

3.7.1 Recommendations for use of the US

While US imaging is reliable for resting thickness measurements, these were recorded with participants positioned in supine - relaxed and fully supported. Although it may be presumed that measurements of resting thickness in different positions such as sitting or standing should be reliable, the increased demand on control mechanisms in order to maintain upright positioning, may produce additional variability with repeated measurements. It is recommended that reliability of US imaging of abdominal muscles in different positions be determined.

Results of the current study suggest that thickness measures during contracted states may be reliable across repeated attempts however it is recommended that attention is given to standardising the activity. The current study hypothesised those discrepancies both within subjects as well as between subjects may be responsible for the lower ICC scores seen during contracted states.

The following recommendations for improvements in assessment protocol are suggested when using ultrasound imaging for investigating abdominal musculature in children:

- for studies investigating effect of intervention the same rater/tester should be used for pre and post intervention testing.
- for studies investigating change in muscle thickness during isometric activity, standardising the activity should be considered in order to allow for more reliable comparison between and within subjects.
- as current evidence suggests varied recruitment across multiple attempts, observational or 3D movement analysis of the activity should be done to investigate correlation between movement parameters, quality of movement and pattern of abdominal muscle activation.
- stability of the thickness measurements needs to be determined for different populations in order to identify real difference over time when investigating effect of intervention.

3.7.2 Recommendations for future research

The following recommendations are suggested as areas for future research:

- Establishing norms for resting muscle thickness measurements of all four abdominal muscles across the ages in children with TD which will allow for more accurate comparison with children with pathology.
- Similarly comparison of muscle thickness measurements with other paediatric populations and investigation into the relationships between thickness measurements and posture and function will contribute to an understanding of possible factors related to motor dysfunction in children with pathology.
- Magnetic resonance imaging (MRI) may assist in the description of abdominal muscle anatomy in children. Do the same morphological changes (increased stiffness and shortening of muscle) that have been reported in the limb musculature in children with increased tone (refer to 2.4) occur in the abdominal muscles and to what extent does this impact on functioning?
- The relationship between resting thicknesses, percentage change during selected activity, posture and function needs to be determined.
- Using surface electrodes EMG activity of at least the superficial abdominal muscles (RA and OI) may verify the assumption that thickness measurements are related to strength and or functional ability.
- More stringent in- and exclusion criteria for selection of participants when investigating the abdominal musculature, regarding potential confounders such

children's level of activity and participation (ICF) is recommended when establishing norms.

- Measurement of resting thickness in other positions such as in the standing and or seated positions and correlation with functional activity is recommended. M-mode US imaging^{83;319}(refer to 2.6.3.2) during walking may also provide relevant information relating to abdominal muscle activity during gait function.

3.8 Conclusions

The current study provides evidence that ultrasound imaging is a reliable instrument for the description of abdominal muscle thickness in the supine position during rest and during selected (sub maximal) activity in children with TD aged six to thirteen years as well as in age matched children with STCP. The measurements of all muscle groups are more reliable in children with STCP and reliability can be enhanced if the same tester takes the repeated measures. In addition it would appear that the measurement technique may be reliable but the variance across measurement occasions may be due to a difference in patterns of recruitment from one session to the next. The relationship between thickness measurements of the abdominal muscles and posture and or function however still needs to be established.

Preliminary analysis suggests differences in abdominal muscle thickness measurements exist between children with TD and children with CP (further investigated in Chapter 4). Thickness measurements in children with STCP are more stable over repeated attempts compared to children with TD and US imaging may therefore provide a valuable tool for describing strategies used by children with CP for motor function. Should a significant relationship between abdominal muscle activity and gross motor function exist (further explored in Chapter 5), responsiveness or sensitivity of the US imaging and measurement to detect smaller differences or changes in these muscles in children with pathology would need to be demonstrated.

In children with TD the results suggest that the resting thickness of all four abdominal muscles (TrA, OI, OE and RA) correlates significantly with age and body stature. Whether this relationship exists in children with pathology still needs to be investigated. The current study also demonstrates that the muscle thickness is a stable variable over short periods of time and the calculation of the SRD provides estimates of effect size

needed in order to conclude efficacy following intervention. This information can also be used to calculate sample sizes when investigating efficacy of a trunk targeting intervention studies in which US imaging is used as outcome measurement.

Investigation into abdominal muscle thickness in children with cerebral palsy and children with typical development

4.1 Introduction

Chapter 3 showed that in children with typical development (TD) the resting thickness of each of the four abdominal muscles correlated significantly with age and body stature. In children with cerebral palsy (CP) however when compared to their age-matched peers, growth patterns due to the underlying impairments affecting development of normal bone and muscle structure have been found³⁵⁴. Although these growth patterns vary among the different types of CP, they become more common and prominent with increasing severity³⁵⁵. Differences in muscle size and consequently strength and recruitment patterns between children with TD and children with motor dysfunction can therefore be expected. It could be hypothesised that children with CP due to the generally lower level of functional activity may accordingly present with thinner and weaker abdominal muscles than children with TD (refer to 2.4.2). Relationships between age and body stature in children with CP have also not yet been explored.

Posture affects muscle length and consequently its ability to contract. Kim et al. (2006) demonstrated in adults that an increased lumbar lordosis is significantly related to flexor - extensor imbalance in the trunk and concluded that an imbalance in trunk muscle strength can significantly influence the lordotic curve of the lumbar spine and might be one risk factor for potential low back pain¹⁰⁹. In persons with CP the excessive anterior tilt and increased lordotic curvature commonly seen in standing and during gait may stretch the abdominal muscles also influencing their ability to contract and provide stability to the trunk.

Appropriate interaction of both the local and global stabilising systems (refer to 2.2.2) is essential for efficient trunk stability¹⁰¹. Using ultrasound imaging (US) in adults researchers have shown that over activity of the global system or inactivity in the local system – particularly in the transversus abdominis (TrA) - decreases the stability of the lumbar spine. Excessive co-contraction between flexors and extensors of the trunk is

reported in children with CP^{49;119} and it is hypothesised that this is a compensatory strategy for weak peripheral musculature⁴⁹. It may however also be due to inactive TrA (local system) activity. Results from Chapter 3 show that children with TD use varied strategies between repeated attempts of the same activity. Children with STCP however were more consistent and both groups of children demonstrated minimal recruitment of the TrA and obliquus internus (OI) for stabilising the spine during activity recorded in the supine position. Whether these differences are significant however still needs to be determined.

The level of activity as recorded by electromyography (EMG) in selected abdominal muscles has been shown to differ between adult males and females in that females presented with a higher level of co-contraction between the abdominal muscles and trunk extensors during a body-tilt exercise. Similarly higher activity levels in the abdominal muscles were recorded in females, while males recorded higher levels of activity in the trunk extensor muscles¹¹². Results from the regression analysis conducted in Chapter 3 show that gender is predictive of the resting thickness of the OI and OE muscles in children with TD (refer to 3.4.1.5). Whether similar differences exist between boys and girls in children with STCP is currently unknown.

The primary aim of the study was to compare children with TD to children with CP to identify systematic differences in abdominal muscle structure and recruitment activity which may be related to the underlying health condition. As US imaging was shown to be a valid and reliable instrument for investigating abdominal muscle activity in children (Chapter 3), this study utilised thickness measurements of all four the abdominal muscles to identify these differences. Reliability of US imaging for measuring abdominal muscle thickness in the standing position however is still unknown and was also examined in this study.

4.2 Aims and objectives

In a group of children with TD and in a group of children with STCP between the ages of six and 13 years, the specific objectives of the study were to:

- describe and provide preliminary baseline measurements for the thicknesses of TrA, OI, OE and RA muscles during resting (*as recorded by ultrasound imaging(US) in the supine position*) and active state (*during head-up activity*)
- compare the above measurements to establish if there are significant differences between the two groups of children
- determine any differences between boys and girls within each group for resting muscle thickness measurements and regarding pattern of recruitment of abdominal muscles

This study furthermore aimed, in the group of children with STCP to:

- determine whether there are differences in resting muscle thickness between children with diplegic and hemiplegic type CP
- compare left and right side abdominal muscle thickness measurements in children with diplegia and 'non- or unaffected' side with the 'affected' side in children with hemiplegia
- to determine whether a significant correlation exists between age and body stature and resting abdominal muscle thickness measurements in that it could be assumed that older children with CP and with larger body stature could have thicker muscles

Measurements of the abdominal muscles in the supine position could be expected to differ when compared to thickness measurements in other positions. In the same group of children with STCP, this study therefore also aimed to determine whether:

- resting thickness measures recorded in the supine position are reliable
- differences exist between the thickness of the four abdominal muscles as measured in a supine position compared to thickness as measured in a standing position during rest and during activity
- differences exist between the percentage change calculated during activity (difference between resting and activity) in the standing and supine positions

4.3 Methodology

4.3.1 Study design

The study design selected for the description and comparison of abdominal muscle thickness measurements in children with TD and in children with STCP was a cross-sectional, descriptive, correlational design.

4.3.2 Hypothesis

The following null hypotheses were tested:

- No significant differences in abdominal muscle thickness measurements exist between children with TD and children with STCP during rest or contracted states. The expectation was however, that children with TD will have thicker abdominal muscles than children with CP.
- No differences exist in resting muscle thickness or in patterns of recruitment (percentage change in thickness of each abdominal muscle) between boys and girls in either group.
- No significant relationships exist between age and body stature and muscle thickness measurements in children with STCP
- In children with STCP no significant difference in muscle thickness measurements exists between the two sides of the body, regardless of which side is more or less affected.

The expectation was however, that in children with diplegia no difference would exist between left and right sides, while in children with hemiplegia the muscles on the affected side would be thinner than on the unaffected side.

- In children with STCP muscle thickness measurements during rest in supine will not be thicker than abdominal muscle thickness measurements in standing. The expectation was however, that some of the abdominal muscles would be thinner in standing due to the change in biomechanical alignment of the spine and pelvis i.e. increased lumbar lordosis and anterior pelvic tilt.

4.3.3 Subjects and sampling

The same two populations from which the groups were selected for the previous study that investigated the reliability of ultrasound imaging (refer to 3.3.2) were selected for recruitment into the current study.

To be included in the study all children:

- had to be present on day of testing
- were between the ages of six and 13 years old

Furthermore children with CP also had to meet the following criteria to be included in the study:

- present with either spastic diplegia or hemiplegia as diagnosed by the school paediatrician
- ambulant with or without a walking aid or with or without orthoses
- classified as either Level I, II or III according to the Gross Motor Function Classification Scale (GMFCS)^{5;192} by the researcher, a trained NDT paediatric physiotherapist

Although children with GMFCS III may need upper limb support to maintain standing and it could be argued that comparing posture with those who stand independently is inappropriate, these children were considered for inclusion. The testing protocol attempted to standardise the procedure by having *all* children place their hands on the parallel bars to be used as support as needed (refer to 4.3.4.3).

Children had to be healthy on the day of testing (as self-reported). They were excluded from the study if their BMI exceeded 25kg/m² (refer to 3.3.2). Children with TD were also excluded if they had any formal diagnosis affecting motor function such as developmental coordination disorder, attention deficit and hyperactivity disorder etc. Children with CP were excluded from the study if they had any other diagnosis affecting motor function such as athetosis, ataxia or dystonia. Any potential participants who had surgery or any spasticity altering procedures within the previous twelve months were also excluded.

A sample size calculation used the data related to the TrA muscles in children with TD from the reliability study (Chapter 3). This measure was selected as the functioning of the core stabilisers - in particular that of the TrA - was considered key contributor to

improved motor performance. A sample of 31 subjects needed to be recruited into each group using the mean value of 2.59mm, (SD 0.68) to detect an expected difference of 0.5mm, a power level of 80% and a significance level of .05 (Statistica, Version 9).

The data from the group with TD were taken from the reliability study. In contrast, new data from the children with CP were gathered a year later. Twenty seven children who met the inclusion criteria following screening by the physiotherapists at the school were invited to participate - many of whom had participated in the reliability study. As the sample size calculation suggested 31 children should be included in the study, the data from ten children who had participated in the reliability study but who were not included in the 'new' group was added. These children either exceeded the age limitations, had surgery in the past year or had left the school. Thirty seven children with STCP (N=37) were ultimately included in this study.

4.3.4 Procedure

Approval for this and the previous study as described in Chapter 3 was obtained from the Human Research Ethics Committee at the University of Cape Town (414/2006), the Department of Education^{viii} and head of the school where the study was conducted. For the second set of testing of the children with STCP information leaflets and consent forms (Appendix 2) were sent home with the learners who met the criteria for inclusion. Those learners who signed the assent form and whose parents signed the informed consent were finally included in the study.

4.3.4.1 Instrumentation

The same instruments used to capture, measure and record data relating to demographics, anthropometric- and abdominal muscle thickness in Chapter 3 were used in the current study, namely:

- A data collection sheet drawn up in Excel which allowed for the recording of age, gender, diagnosis, grade, height, weight, body mass index and thickness measurements for all four abdominal muscles.

^{viii} Directorate for Education Research

- A Siemens® Accusonic X150 ultrasound imaging machine with a 5.5cm wide band linear array frequency of 5Hz which was used to capture B-mode (2-D) real-time images of the four abdominal muscles. Conductive gel was used between the transducer and the skin.
- Height was measured as described in Chapter 3 (refer to 3.3.5) using a standard tape measurement attached to a wall.
- Weight was measured using a calibrated SALTER Personal Fitness Plus Scale (UK) (model 9191).
- BMI was calculated using mass (kg)/height (m)².

4.3.4.2 Location

A small private therapy room in the Physiotherapy Department was temporarily equipped with a plinth and used for the second round of data collection in children with STCP. Participants were tested during school hours and participants from the same class accompanied each other during the testing sessions.

4.3.4.3 Testing procedure

A research assistant^{ix}, trained by the researcher in US imaging captured all the images. Resting and head-up activities were first performed in the supine position. The second set of images was then captured with the participant in a standing position between parallel bars. First a resting image was captured - on the right side only in children with spastic diplegia and on the affected side in children with hemiplegia – followed by an image captured during a leg lift activity of the contralateral leg. Participants were barefoot and instructed to use the bars only for support as necessary (Figure 11).

Capturing images in the supine position

The same procedure for testing and recording thickness measurements during rest and during the head-up activity described in Chapter 3 (refer to 3.3.3.4) was followed in the current study. Images were captured on both sides. The tester made every effort not to apply too much pressure through the transducer while testing. All images were stored for later analysis.

^{ix} Qualified NDT trained physiotherapist

Capturing images in the standing position

Participants were asked to stand between the parallel bars facing forward, and as upright as possible (Figure 11). No external support other than allowing participants to touch the bars as lightly as possible was allowed or given. Each participant was tested as follows:

A resting image of the three lateral abdominal muscles was captured on end-inspiration as observed by the tester with the transducer in *Position 1* as described in Chapter 3 (refer to 3.3.3.4). The second measurement required lifting the contralateral leg (i.e. flexing the hip and knee to approximately 90°) (Figure 12). This activity was selected in order to apply sub-maximal resistance to the trunk musculature. Participants were asked to keep the trunk as upright as possible and to only move the leg. Participants were permitted to hold onto the bars more tightly for support if necessary to assist in preventing movement of the trunk. They were then told to hold the position and the image captured. Following a one minute rest a resting image for RA, with the transducer in *Position 2* (refer to 3.3.8) was captured at end-inspiration as well as for the leg lift activity as described above. In the standing position images were only captured on one side – the right side in children with diplegia and the affected side in children with hemiplegia.



Figure 11 The standing position for capturing US images at rest



Figure 12 The standing position for capturing US images during the leg lift activity

Data recorded during rest in the standing position was analysed to inspect test-retest reliability in a random selection of ten children participating in the current study. Repeated measurements by the same tester on the same day were conducted as described in the testing procedures above. Intra-class correlation coefficients (ICC) (Statistica) were used to determine agreement between the two measurements (refer to 3.3.5). Although no sample size calculation was conducted the results of these ten subjects' shows acceptable ICC values for resting thickness measurements recorded in standing (Table 12) which was in line with results obtained for the measures recorded in supine. As it was also not necessary to eliminate any images and / or measures exceeding the $>2SD$ criterion, nor was the 7.5% difference between measurements exceeded. The lower ICC scores for the resting measurement of RA suggest poorer reliability than for measurements recorded in the supine position. Due to the small sample size (also the reason for the wide spread of the confidence interval), this lower score was accepted in the current study. Although it was assumed that lesser variability in movement patterns reported in children with CP would also apply to this activity, the less stable nature of the standing position may influence recruitment strategies across repeated attempts. Results however suggest consistency between attempts (Table 12).

Table 12 Test-retest reliability of resting abdominal muscle thickness measurements (Intraclass Correlations Coefficients) recorded in the standing position (n=10)

Muscle		ICC	95% Confidence Interval	SEM
TrA	rest	0.830	0.466 ; 0.955	0.19
	leg lift	0.732	-0.075 ; 0.945	0.15
OI	rest	0.857	0.063 ; 0.971	0.30
	leg lift	0.859	0.509 ; 0.964	0.51
OE	rest	0.871	0.583 ; 0.966	0.34
	leg lift	0.911	0.691 ; 0.977	0.40
RA	rest	0.691	0.194 ; 0.911	0.44
	leg lift	0.897	0.639 ; 0.973	0.23

4.3.5 Measurement and data processing

All the data recorded for children with TD relating to abdominal muscle thickness measurements recorded during rest and head-up activity were used in the current study. For the children with STCP the images recorded during the second round of testing as described above were used and the same procedure for measurement of the thickness of the four abdominal muscles as described in Chapter 3 was followed. Three thickness measurements for each muscle were recorded and averaged for each image captured and stored for later analysis.

In order to allow for later comparison between the left and right sides in subjects with hemiplegia the hemi side was processed to be the 'right side'. In other words in subjects with hemiplegia the affected side is being compared to the 'normal' or unaffected side, while in subjects with diplegia, the right side is compared to the left side.

The percentage difference between resting and the head-up activity was calculated – $[(\text{head-up thickness} - \text{resting thickness}) / \text{resting thickness} * 100]$ for all four abdominal muscles in both groups of children to allow for comparison between subjects and for investigation into patterns of recruitment of the abdominal muscles.

4.3.6 Statistical analysis

Data processing and analysis was conducted using Statistica (Version 9). The sample was described using descriptive statistics. Where the distribution was normal according to the Kolmogorov-Smirnov, the mean and standard deviation (SD) for demographic data and anthropometric measurements were reported. Differences between anthropometric- and thickness measurements in children with TD and with STCP were estimated with a two-way, mixed effects model ANOVA. Mann Whitney-U tests were used to investigate differences in muscle thickness between male and females. Standard multiple regression analysis was used to identify which variables were predictive of resting muscle thickness. Dummy variables were created for male/female and STCP/TD - these together with age and BMI were entered. Residual analysis was done and cases that were more than $1.96 \times \text{SD}$ away from the mean (outliers) were excluded in the final model.

4.3.7 Ethical considerations

Approval was obtained from the relevant ethical review boards. Autonomy was ensured in that subjects volunteered to participate and they were only recruited if written informed consent was obtained from their parent(s) or legal guardian. The subjects were able to withdraw at any time, all data was processed anonymously and copies of the images captured were printed and given to the learners. Separate written informed consent is/will be obtained from participant and their legal guardian for any images used in publication(s) and or academic presentations. Measurements were taken with due regard to the dignity of every individual in that only the abdominal muscles were exposed and the location utilised allowed for privacy. As there were no known risks associated with any of the procedures conducted, the principle of non-maleficence was adhered to. No costs were incurred by participants. Although the all learners at the school selected for participation came from traditionally disadvantaged backgrounds, the principle of justice was not violated as there were no known risks or benefits of taking part in the study. Results were made known to the therapists at the school and to those parents who requested information.

4.4 Results

Following a description of the sample demographics and anthropometric measurements, preliminary baseline measurements are reported for children with TD and for children with CP for all four abdominal muscles. The differences between males and females in both groups regarding resting muscle thickness and pattern of abdominal muscle recruitment is then investigated. A more detailed report is also given for children with STCP of the differences in the thickness of the four abdominal muscles as measured in the supine and standing positions. Differences in abdominal muscle thickness measurements between children with diplegic and hemiplegic CP as well as comparison between the right and left sides ('affected' and 'non- or less affected' sides) will conclude this section.

4.4.1 Demographic characteristics and anthropometric measurements

For the group of children with TD the data of all 89 subjects that participated in the reliability study (Chapter 3) was used in the current study. There were 46 males and 43 females enrolled. In the group of children with STCP, 34 subjects were ultimately recruited into the study. The parents of three potential subjects did not consent to participation. There were 21 males and 13 females enrolled. Nineteen participants were diagnosed with spastic diplegia, 15 presented with hemiplegia.

The average age, height, body mass and BMI of all participants in the current study can be seen in Table 13. Although the average age was higher for children with CP by up to almost a year than for the children in the group with TD, this was not significant ($p=0.07$). Similarly children with CP were shorter and had a lower body mass than children with TD, but none of these differences were significant. Because no significant difference was found between the two groups for any of these variables, no stratification and matching was necessary and all participants were included in further analyses.

Table 13 Age, height, weight and BMI comparison between children with CP (n=34) and with TD (n=89)

Characteristic		CP		TD		p value	
		mean	SD	mean	SD		
age (years)		10.36	2.07	9.64	1.83	0.07*	*T-test
height (m)		1.39	0.12	1.43	0.14	0.39*	
weight (kg)		31.62	7.56	35.93	10.40	0.09*	
BMI (kg/m ²)		16.34	2.78	17.22	2.55	0.11*	
gender	female	13		43		0.32**	**Chi-square
	male	21		46			

In both groups of children the boys did not differ from the girls with respect to age, height, weight or BMI ($p > 0.05$ for all variables).

4.4.1 Baseline values for resting muscle thickness

Baseline values for resting muscle thickness (mm) for both children with TD and with CP are reported in Table 14. The OI muscle in children with CP is 23.5% thicker ($p < 0.01$) when compared to those in children with TD. Children with CP also have significantly thicker OE ($p = 0.015$) and RA ($p = 0.02$) muscles when compared to children with TD. No significant difference was however found for the TrA muscle between the two groups (Table 14).

Table 14 Baseline values for resting muscle thickness (mm) in children with TD and CP

muscle	CP			TD			CP vs TD		
	N	mean (mm)	SD	N	mean (mm)	SD	t-value	df	P*
TrA	34	2.64	0.64	89	2.59	0.68	0.35	121	0.726
OI	34	6.25	1.62	89	5.06	1.69	3.54	121	0.001
OE	34	3.74	1.23	89	3.22	0.95	2.48	121	0.015
RA	34	5.79	1.12	89	5.21	1.27	2.35	121	0.020

*t-test for independent samples

In children with TD a pattern of descending order of relative thickness was found with RA >OI > OE > TrA, while in children with CP the pattern of thickness showed OI > RA > OE > TrA.

No significant differences were found by the Mann Whitney U test for any of the four abdominal muscles between boys and girls in either group regarding resting muscle thickness, except in children with TD where girls had significantly thicker OI muscle (6.3mm SD=1.5) when compared to boys (6.1mm SD=1.8) ($p=0.014$).

4.4.1.1 Comparison of resting muscle thickness in supine and standing in children with STCP

The data of all 27 participants (refer to 4.3.3) was entered into the analysis. In standing the mean resting thickness measurements for the TrA, OE and RA muscles were significantly smaller than the means recorded at rest in supine (Table 15). No difference was found for the resting thicknesses of the OI muscle in the supine and standing positions, but similar to the other muscles, the standing measurement was reduced.

Table 15 Comparison of resting muscle thickness between supine and standing positions in children with STCP (n=27)

Muscle	position	Mean resting thickness (mm)	SD	p value
TrA	supine	2.67	0.58	0.042*
	standing	2.39	0.53	
OI	supine	6.33	1.58	0.27
	standing	6.01	2.18	
OE	supine	3.87	1.24	<0.001*
	standing	3.21	0.85	
RA	supine	6.11	1.08	0.011*
	standing	5.70	1.08	

* $p < 0.05$

4.4.2 Pattern of recruitment

An independent t-test was done in order to determine whether there was a significant difference between the resting and head up activities for the group of children with CP (Table 16). For children with STCP only the RA muscle was significantly thicker during

contraction when compared to the resting state ($p < 0.00$). Significant difference between contracted and relaxed state was also found for the OE muscle in that it was thinner during contraction compared to at rest (Table 16). The differences recorded between resting and head-up activities in the group of children with TD (refer to 3.4.1.4) were significant for all four muscles. Similarly difference recorded for the OE muscle also suggests that the muscle was stretched or compressed during the head-up activity.

Table 16 Dependent t-test for detection of difference between resting and head up activity in STCP (n=34)

Activity: muscle	Mean	SD	N	Diff.	SD	t	df	p value
resting: TrA (mm)	2.64	0.64						
head-up: TrA (mm)	2.63	0.73	34	-0.01	0.48	-0.14	33	0.891
resting: OI (mm)	6.25	1.62						
head-up: OI (mm)	6.21	1.72	34	-0.04	1.04	-0.23	33	0.821
resting: OE (mm)	3.74	1.23						
head-up: OE (mm)	3.40	1.13	34	-0.34	0.68	-2.94	33	0.006*
resting: RA (mm)	5.79	1.12						
head-up: RA (mm)	7.62	2.04	34	1.83	1.35	7.91	33	<0.000*

* $p < 0.01$

In order to investigate the potential range of contraction in children with STCP, measurements from resting to contracted state were compared between children with TD and children with STCP using ANOVA with a mixed models approach. For the OI muscles (Figure 13) there was no difference between thicknesses recorded during the head-up activity, suggesting that during contraction children with CP attained similar maximal thicknesses and therefore shorter range of contraction. Figure 14 confirms the lack of ability to contract the TrA in children with STCP. No significant interaction between the two groups of children during contraction of the OE ($p = 0.654$) and RA ($p = 0.300$) muscles was found and despite being thicker in children with STCP, similar range of contraction was seen with for the OE and for the RA muscle.

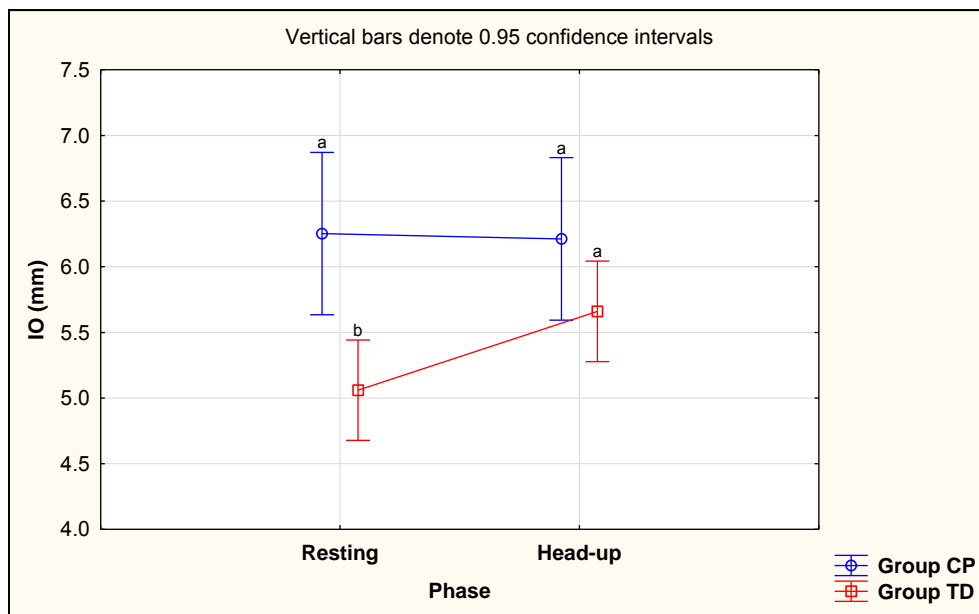


Figure 13 Comparison between children with TD and CP for range of contraction in the IO muscle (thickness measurements: time*group; LS means ($p=0.0.002$))

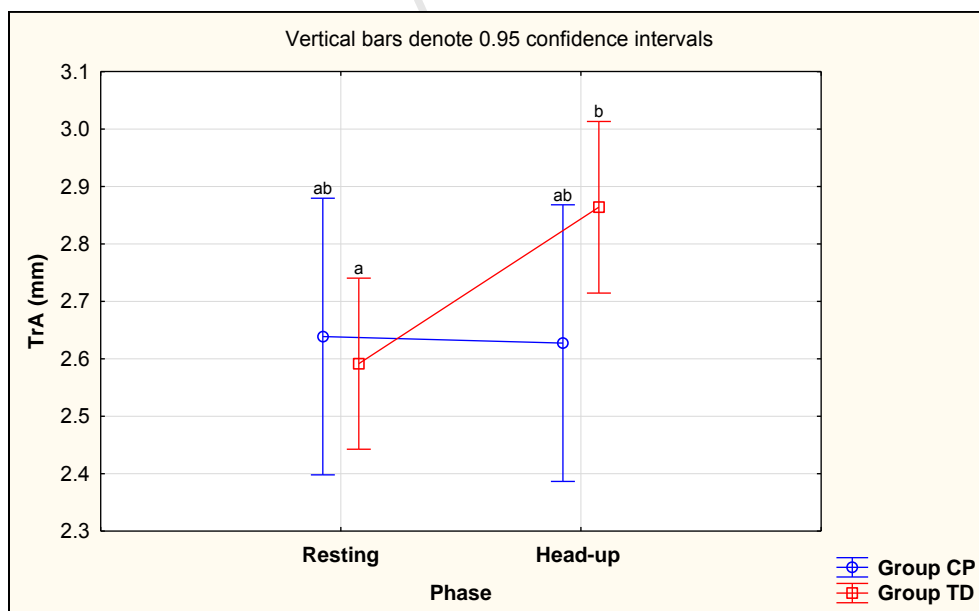


Figure 14 Comparison between children with TD and CP for range of contraction in the TrA muscle (thickness measurements: time*group; LS means ($p=0.0.008$))

The percentage difference between the resting and head-up activity thickness measurements was calculated for all four abdominal muscles in both groups and compared. Table 17 indicates that the percentage change that occurred in the TrA, OI and RA muscles between active and resting states in children with TD was significantly more than for their peers with STCP. In both groups the OE muscle was thinner in the contracted state than in the resting state, but the difference between the two groups was not significant.

Table 17 Comparison of percentage change in muscle thickness from resting to head-up position between children with TD and CP

Muscle	CP (n=34)		TD (n=89)		p value
	mean (%)	SD	mean (%)	SD	
TrA	0.4	17.1	12.0	21.8	<0.01*
OI	0.3	16.6	12.4	21.1	<0.01*
OE	-7.8	18.2	-10.9	25.9	0.19
RA	31.2	22.4	43.6	31.4	0.05*

***p<0.05**

4.4.2.1 Gender differences in percentage change in muscle thickness

No significant differences were found for any of the four abdominal muscles between boys and girls in either group regarding percentage change in muscle thickness during contracted state except for boys in the group of children with TD who recorded a significantly higher percentage change in the RA muscle (51% SD=33) than girls (35%, SD= 28) during the head-up activity (p=0.015).

4.4.2.2 Comparison of percentage change in the supine and standing positions in children with STCP

The means of the percentage change following activity indicate that in the standing position all four abdominal muscles are recruited during the leg lift activity compared to the supine position where only the mean for the RA during the head-up activity showed a positive change i.e. increase in thickness during the contracted state (Table 18).

Table 18 Comparison of % change in muscle thickness between supine head up (HU) and standing leg lift activity (n=27)

Muscle	Activity	mean % change	SD	p value
TrA	<i>Supine resting to HU</i>	-5.1	15.0	<0.001*
	<i>Standing resting to leg lift</i>	32.4	36.3	
OI	<i>Supine resting to HU</i>	-7.4	16.9	0.031*
	<i>Standing resting to leg lift</i>	12.6	29.6	
OE	<i>Supine resting to HU</i>	-3	13.6	0.089
	<i>Standing resting to leg lift</i>	7.8	19.4	
RA	<i>Supine resting to HU</i>	27	21.8	<0.001*
	<i>Standing resting to leg lift</i>	3.4	10.6	

* $p < 0.5$

4.4.3 Differences in resting abdominal muscle thickness measurements between children with diplegia and children with hemiplegia

No significant differences were found for the resting thicknesses of all four abdominal muscles as measured on the right side in children with diplegia when compared to the measurements recorded on the affected side in children with hemiplegia, although in all cases the affected side in children with hemiplegia was thicker (Table 19).

Table 19 Comparison of resting abdominal muscle thickness measurements (mm) between hemiplegia and diplegia (n=34)

Muscle	Diagnosis	n	mean thickness (mm)	SD	p value
resting TrA	hemiplegic	15	2.74	0.71	0.293
	diplegic	19	2.51	0.54	
resting OI	hemiplegic	15	6.67	1.54	0.093
	diplegic	19	5.73	1.63	
resting OE	hemiplegic	15	3.98	1.12	0.193
	diplegic	19	3.43	1.32	
resting RA	hemiplegic	15	5.91	0.98	0.484
	diplegic	19	5.63	1.30	

4.4.4 Comparison of resting abdominal muscle thickness measurements between sides in children with STCP

The abdominal muscle thickness measurements on both sides were compared in children with diplegia and hemiplegia. In children with diplegia no significant difference was found between the left and right sides. In children with hemiplegia however significant difference was found between the affected side and the non-affected side in the OI muscle. Although not significant the mean for RA on the unaffected side in this hemiplegic group was higher than for the mean for the affected side (Table 20). For the total CP group two way ANOVA analysis did however show a significant interaction between side and diagnosis for the RA muscle ($p=0.04$) suggesting that there is a difference in thickness between left and right sides in children with STCP.

Table 20 Comparison between left and right side abdominal muscle thickness measurements for hemiplegics ($n=12$) and diplegics ($n=15$)

Diagnosis	Muscle	side	mean (mm)	SD	N	Diff. (mm)	SD (diff.)	t-value	p
Hemiplegia	TrA	affected	2.56	0.58					
		non-affected	2.42	0.47	12	0.15	0.57	0.894	0.391
	OI	affected	6.00	1.56					
		non-affected	5.33	1.40	12	0.67	1.02	2.275	0.044*
	OE	affected	3.69	1.27					
		non-affected	3.62	1.12	12	0.07	0.61	0.411	0.689
	RA	affected	5.93	1.24					
		non-affected	6.21	1.28	12	-0.28	0.53	-1.843	0.092
Diplegia	TrA	R	2.77	0.71					
		L	2.75	0.62	15	0.02	0.51	0.135	0.895
	OI	R	6.72	1.33					
		L	6.30	1.12	15	0.42	0.89	1.836	0.088
	OE	R	4.03	1.21					
		L	3.95	1.00	15	0.08	0.77	0.400	0.695
	RA	R	6.07	1.04					
		L	5.95	1.16	15	0.12	0.72	0.659	0.521

* $p < 0.05$

4.4.5 Correlation between muscles thickness and gender, age, height, weight and BMI

Pearson's r using data recorded on the right side only (in children with CP this included the affected side in hemiplegia and right side in diplegia – refer to 4.3.4.3) show that:

Gender For children with TD, boys had a significantly thicker resting OI muscle compared to girls ($p=0.02$) while there was no significant difference found between them for the other three abdominal muscles. No significant difference was found between boys and girls with STCP and any of the abdominal muscles.

Age While for children with TD a significant correlation existed between age and resting abdominal muscle thickness measurements, no correlation for this variable in children with STCP was found.

Height, Weight and BMI For children with TD a similar significant correlation existed for height, weight and BMI and resting abdominal muscle thickness measurements with $p<0.001$ for all measurements. In children with STCP however only height correlated significantly with the RA and OE resting muscle thickness measurements ($p<0.01$). Furthermore significant correlation was only found for TrA and RA muscles and weight and for TrA and BMI ($p<0.01$).

4.4.6 Variables predicting muscle thickness in each group

4.4.6.1 Children with TD

To determine predictor variables of resting muscle thickness in children with TD age, gender and BMI were ultimately entered into the model for multiple regression analysis. These analyses resulted in models which explained from 27% (RA) to 47% (OE) of the variance. Different variables were found to be predictive of the thickness of the different muscles. Age was a significant predictor in all four abdominal muscles, while gender and BMI were found to be significant predictors of TrA, OI and OE resting muscle thickness but not of RA (Table 21).

Table 21 Regression summaries of variables predictive of resting muscle thickness in children with TD

resting TrA (4 cases eliminated)	b		Std.Err. - of b	t(81)	p	Adjusted R ²
	Intercept	9.29	10.14	0.92	0.362	0.39
	Gender	-0.09	0.10	-0.93	0.355	
	Age	0.06	0.03	2.06	0.043	
	BMI	0.12	0.02	5.40	0.000	
resting OI (1 case eliminated)	b		Std.Err. - of b	t(83)	p	Adjusted R ²
	Intercept	94.3	24.866	3.79	0.000	0.43
	Gender	-0.94	0.245	-3.8	0.000	
	Age	0.38	0.075	5.01	0.000	
	BMI	0.15	0.055	2.73	0.008	
resting OE (5 cases eliminated)	b		Std.Err. - of b	t(79)	p	Adjusted R ²
	Intercept	40.28	14.01	2.88	0.005	0.47
	Gender	-0.41	0.14	-2.93	0.004	
	Age	0.16	0.04	3.62	0.001	
	BMI	0.14	0.03	4.57	0.000	
resting RA (4 cases eliminated)	b		Std.Err. - of b	t(81)	p	Adjusted R ²
	Intercept	13.64	20.29		0.503	0.27
	Gender	-0.12	0.20	-0.60	0.549	
	Age	0.27	0.06	4.46	0.000	
	BMI	0.06	0.04	1.34	0.183	

4.4.6.2 Children with STCP

Various models were tested in children with STCP regression analysis using diagnosis (hemiplegia and diplegia), height and weight and BMI to determine which would be most predictive of resting muscle thickness measurements. The model using age, gender, and BMI produced the highest adjusted R² rating. However even using this model these variables were poor predictors of resting thickness in these children. Only 9% (TrA), 12% (OE) and 10% (RA) of variance could be explained (Table 22) using this model.

Table 22 Regression summaries of variables predictive of resting muscle thickness in children with STCP

resting TrA (0 cases eliminated)	b		Std.Err. - of b	t(28)	p	Adjusted R ²
	Intercept	0.41	0.97	0.42	0.678	0.08
	Gender	0.14	0.22	0.65	0.524	
	Age	0.07	0.06	1.24	0.227	
	BMI	0.09	0.04	2.14	0.041	
resting OI (1 case eliminated)	b		Std.Err. - of b	t(27)	p	Adjusted R ²
	Intercept	-1.48	2.04	-0.73	0.473	0.31
	Gender	-0.28	0.47	-0.59	0.562	
	Age	0.40	0.12	3.34	0.002	
	BMI	0.23	0.08	2.72	0.011	
resting OE (1 case eliminated)	b		Std.Err. - of b	t(27)	p	Adjusted R ²
	Intercept	-0.46	1.72	-0.27	0.792	0.12
	Gender	-0.01	0.40	-0.04	0.971	
	Age	0.24	0.10	2.37	0.025	
	BMI	0.11	0.07	1.56	0.132	
resting RA (2 cases eliminated)	b		Std.Err. - of b	t(26)	p	Adjusted R ²
	Intercept	3.37	1.28	2.64	0.014	0.10
	Gender	-0.16	0.30	-0.54	0.594	
	Age	0.18	0.08	2.30	0.030	
	BMI	0.05	0.05	0.90	0.375	

Using the above model (Table 22) a ten year old female child with STCP with a BMI of 15kg/m² may have an OI muscle measuring 5.7mm (4.9 - 6.5mm) thick while a 13 year old girl with the same body stature may present with an OI muscle measuring 6.9mm (5.9-7.9mm). Alternatively, a small built seven year old boy with a BMI of 14kg/m² will most likely present with an OI muscle thickness of 4.5mm (3.4 - 5.7mm) compared to a much larger boy of the same age but with BMI of 24kg/m² who most likely will present with a much thicker OI muscle – 6.9mm (5.3 - 8.4mm).

4.4.6.3 All children

Standard multiple regression analysis was conducted entering variables group, gender, age and BMI (Table 23), in order to determine their relationship(s) with resting muscle thickness. Using the above model a boy with TD aged ten with BMI 18kg/m² could expect a RA muscle to be 5.2mm (4.9 – 5.4mm) thick, while a boy of the same body

stature and age but who presents with STCP could expect a RA muscle of 5.8mm (5.4 - 6.2mm) thick.

Table 23 Regression summaries of variables predictive of resting muscle thickness in children

resting TrA	b		SE - of b	t(116)	p	Adjusted R ²
	Intercept	-0.22	0.39	-0.55	0.58	0.29
	Group	0.07	0.12	0.61	0.54	
	Gender	0.03	0.10	0.29	0.77	
	Age	<i>0.08</i>	<i>0.03</i>	<i>2.78</i>	0.01	
	BMI	<i>0.12</i>	<i>0.02</i>	<i>5.76</i>	0.00	
resting Oi	b		SE - of b	t(116)	p	Adjusted R ²
	Intercept	-1.83	0.906	-2.02	0.046	0.28
	Group	<i>1.01</i>	<i>0.280</i>	<i>3.61</i>	0.000	
	Gender	<i>-0.71</i>	<i>0.238</i>	<i>-2.98</i>	0.003	
	Age	<i>0.38</i>	<i>0.067</i>	<i>5.64</i>	0.000	
	BMI	<i>0.21</i>	<i>0.048</i>	<i>4.41</i>	0.000	
resting OE	b		SE - of b	t(116)	p	Adjusted R ²
	Intercept	-0.73	0.60	-1.2	0.23	0.33
	Group	<i>0.48</i>	<i>0.19</i>	<i>2.6</i>	0.01	
	Gender	-0.18	0.16	-1.1	0.27	
	Age	<i>0.22</i>	<i>0.04</i>	<i>4.9</i>	0.00	
	BMI	<i>0.11</i>	<i>0.03</i>	<i>3.6</i>	0.00	
resting RA	b		SE - of b	t(111)	p	Adjusted R ²
	Intercept	1.72	0.64	2.69	0.008	0.30
	Group	<i>0.63</i>	<i>0.20</i>	<i>3.17</i>	0.002	
	Gender	-0.09	0.17	-0.54	0.593	
	Age	<i>0.23</i>	<i>0.05</i>	<i>4.88</i>	0.000	
	BMI	<i>0.07</i>	<i>0.03</i>	<i>2.03</i>	0.045	

4.5 Discussion

The results of the current study provide preliminary baseline values for resting thickness measurements of the four abdominal muscles in six to thirteen year old children with typical development and spastic type cerebral palsy. The hypothesis that the abdominal muscles in children with STCP are thinner at rest than their age-matched peers with TD was rejected. In this section differences in children with STCP regarding abdominal muscle thickness during rest and contracted state recorded in

both the supine and standing positions are discussed. Comparisons between sides in this group are also discussed as well as differences between children with hemiplegia and diplegia. Gender differences regarding abdominal muscle thickness measurements and comparison between children with TD and STCP regarding patterns of recruitment are also discussed in more detail. This section concludes with a discussion of the clinical relevance of these findings.

4.5.1 Baseline abdominal muscle thickness measurements

Prior to this study no data was found pertaining to thickness measurements of the four abdominal muscles in children. Data from a study by Rankin et al. (2006) provides preliminary baseline measurements for 123 healthy adults across the lifespan³⁵¹. These findings were similar to the data reported in healthy adults (Table 24) participating in two other studies (one compared thickness measures in healthy adults and those with low back pain³⁴¹, the other compared thickness measures for healthy individuals in different positions⁷⁷) which suggest that Rankin's reported mean values are most likely representative of the average adult population. When comparing the thickness measurements of children with TD six to thirteen years of age, all four of the abdominal muscles are significantly (and proportionately) thinner than those reported in adults (Table 24). Opinions solicited from an anatomist^x, paediatrician^{xi} and a paediatric surgeon^{xii} suggest that the abdominal musculature in children is a 'smaller version' of that seen in adults also supporting the findings of the current study.

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^{xii} Dr R van Toorn *

Personal communication, prior to undertaking this study (2006)

Table 24 Listing of studies and comparison of resting abdominal muscle thickness measurements in healthy adults and children with TD and CP

Studies	N	TrA (mm) mean±SD(*)	OE (mm) mean±SD(*)	OI (mm) mean±SD(*)	RA (mm) mean±SD(*)
Critchley and Coutts (2002) ³⁴¹	24	5.1 ±1.2 (1)	5.9±1.6 (2)	9.3± 4.0 (3)	
Ainscough-Potts et al. (2006) ⁷⁷	30	4.23±0.99		9.62±3.1	
Hides et al. (2006) ³²³	13	7.0±1.5		16.5±2.4	
Rankin et al. (2006) ³⁵¹ males	55	5.4±1.1 (1)	6.7±1.7 (2)	10.2±2.7 (3)	12.5±2.2 (4)
females	68	4.4±0.8 (1)	5.9±1.8 (2)	7.5±1.8 (3)	10.2±1.5 (4)
children (2006) with TD	89	2.59±0.68 (1)	3.22±0.95 (2)	5.06±1.69(3)	5.21±1.27 (4)
children (2008) with CP	34	2.64±0.64 (1)	3.74±1.23 (2)	6.25±1.62 (4)	5.79±1.12 (3)

* rank order in terms of muscle thickness

These findings however only support the assumption that the muscles of children are a smaller version of adults, as far as diameter measures are concerned. Studies describing skeletal muscle architecture have reported that differences exist between children and adults. Although from about one year of age little difference is found in relative fibre composition, differences exist in myosin heavy chains and other muscle protein isoforms³⁵⁶. Skeletal muscles in children due to their longer length in relation to the tendon length have more of a mechanical disadvantage when compared to older adolescents and adults³⁵⁷. As a result children have a higher metabolic cost per kilogram body mass during for example walking or running and children cannot produce the same relative power as adults. These additional architectural parameters were however not investigated in the current study.

As was expected, there was considerable variation among the current sample regarding the thicknesses of all four abdominal muscles. Similarly, sizeable variation between individuals has also been reported for resting thickness measurements within the healthy adult population^{116,351}. In the studies investigating motor control of the abdominal muscles referred to in Table 24 the healthy control groups in the respective studies matched the subjects with chronic pathology in terms of demographic and anthropometric measures, and where lifestyle was further investigated the healthy and or control participants usually led sedentary lifestyles and seldom participated in physical activity or sport. When compared to these studies, a marked difference for resting abdominal thickness can be seen by the measurements recorded in a study by Hides et al. (2006) whose study sample consisted of thirteen healthy male elite cricket

players. Although sample sizes were small in these studies, activities of daily living and participation in sport does seem to affect resting thickness. While the selection of schools for participation in the current study was one of convenience informal questioning regarding partaking in sport did suggest that the group represented children with a wide spectrum of levels of physical activity. These ranged from regular television and computer users to those who participated at all levels of sport including national level in their respective sports. This potential confounder however was unfortunately not investigated in the current study.

The current study also provides preliminary baseline values for resting abdominal muscle thickness measurements in children with STCP. As for children with TD the abdominal muscles are thinner than those reported for adults. The hypothesis that children with pathology which results in poor postural control have thinner abdominal muscles than their age-matched peers however was rejected by the current study. All four abdominal muscles in the group of children with STCP were thicker than in the group of children with TD. These differences were significant for the OI and OE as well as the RA muscles.

There are several possible explanations for the thicker resting measures recorded in these children. Although unlikely, the greater hip flexion in an attempt to 'neutralise' the pelvis in the supine position in children with CP, may have placed the abdominal musculature in a shorter position when compared to children with TD. Secondly the structural changes reported in skeletal muscles - increased fascicle angle, shorter fascicle length and increased collagen – may account for the thicker appearance (\approx pseudo-hypertrophy). Thirdly it has been reported that a significant relationship exists between resting quadriceps thickness and maximum voluntary contraction in adults³⁵⁸ and similarly strength increases have been shown to correlate with an increase in cross sectional area⁶⁸. Assuming this to be true for all human skeletal musculature a conclusion that could be drawn from this study is that in children with STCP the OI, OE and RA muscles may be more active (i.e. stronger in terms of 1 maximum repetition⁶⁸) than those seen in the general six to 13 year old population and that inactivity or weakness of the abdominal muscles may not be the major contributing factor to poor postural control in children presenting with this type of neurological disorder. This assumption however is unlikely as changes in biomechanical alignment, such as the increased anterior pelvic tilt typically observed in children with STCP affects the line of pull of the abdominal muscles. This mechanical disadvantage and the decreased

potential for shortening due to architectural changes may be the reason for the apparent lack of torque production and resultant limb activity or level of performance¹⁸². Measurement of spinal and pelvic angles, muscle strength and investigation into the relationships between these parameters and function is recommended.

Another difference between children with TD and those with CP is the order of relative thickness of the four abdominal muscles. Children with TD present with similar ascending rank order when compared to adults (Table 24). In children with STCP however the OI is the thickest while in children with TD the RA is the thickest muscle suggesting that children with CP possibly recruit the OI muscle - a core stabiliser muscle - more during daily activity despite poorer motor functional ability. The thicker RA muscle in children with TD suggests that this muscle is the preferred and most likely more frequently used muscle in these children. In adults the RA is also the thickest muscle³⁵¹. Although recruitment patterns differ between individuals and are influenced by changes in body position¹⁰⁴, a thicker RA muscle is not unexpected as this muscle is also used in all global movements of the trunk during activity of daily living⁶⁸. Rigidity and/or fixation of the trunk and associated restricted freedom of movement in the trunk seen in CP may account for the thicker IO muscle and proportionately thinner RA muscle.

According to Rankin et al. (2006) males have significantly larger muscles than females. Even when normalised for body mass, the TrA and RA muscles are significantly larger than those in females³⁵¹. Although in the current study abdominal muscle thickness measurements were not normalised for body mass –as there were no significant difference between boys and girls for this variable - in children only the OI muscle differed significantly between genders with girls presenting with thicker OI muscles than boys. The thicker OI muscles seen in girls with TD may suggest that girls recruit this muscle more during activity and may therefore be stronger than compared to boys. While these higher levels of activity in the abdominal muscles have been reported in female adults when compared to males¹¹², investigating the relationship between level and type of physical activity and the thickness of these muscles is warranted as both boys and girls of this age typically participate in vigorous activities and girls either recruit the OI as mover and or stabiliser more effectively than age matched boys or the type of activity in which girls are more likely to participate (such as netball, rope skipping etc.) targets the OI muscle more. No gender differences for thickness measurements in any of the other abdominal muscles were found. In children with

STCP gender was also not related to resting abdominal muscle thickness. Potential differences between boys and girls in level of physical activity in children with CP are most likely reduced by the impairments associated with the diagnosis^{151;199}. These relationships and whether these similarities extend into adulthood in the CP population, still needs to be investigated.

4.5.2 Differences in resting muscle thickness between left and right side involvement in children with diplegia and hemiplegia

Left and right sided dominance as well as participation in certain types of sport may result in thicknesses differing between the left and right sides^{351;359}. Only the right side was measured in children with TD and therefore comparison between sides in this group was unfortunately not possible. In children with hemiplegia - as anatomically the limbs on the affected side are commonly smaller than the unaffected side⁸⁷ - it was hypothesised that the muscles of the trunk on the affected side would also be thinner than the unaffected side. However, similar to the findings where abdominal muscle thickness measurements in children with CP were thicker than those in children with TD, the OI muscle on the affected side in children with hemiplegia was significantly thicker than the unaffected side. Although not significant, the means recorded for the TrA and OE muscles were also thicker on the affected side, while the mean for the RA muscle was thicker on the unaffected side. As in children with TD whose RA was also thicker than the OI muscle, these results suggest that this muscle unlike the other 'affected' muscles, is predominantly recruited during function. Further investigation into recruitment strategies in children is recommended.

In children with diplegia despite bilateral involvement, the left and right sides may differ in that asymmetry is commonly observed in these children¹⁷¹. Anthropometric asymmetry due to common secondary complications such as spinal deformities and leg length discrepancies³⁰ may exacerbate the difference between the dominant and non-dominant sides. Unfortunately in the current study, unlike in the group of children with hemiplegia where the affected side could be compared to the unaffected side, dominance and other variables contributing to asymmetry were not investigated in this group of children with diplegia. No significant differences in resting thickness were found for any of the muscles when comparing the left and right sides. Children with a lower classification level than the ambulant participants in the current study may

present with greater asymmetry and therefore a larger difference between the two sides may be found. This still needs to be investigated.

4.5.3 Pattern of recruitment

The difference in thickness recorded between resting and contracted states differs significantly between children with TD and STCP. During the head up activity in the supine position children with TD recorded significant differences between resting and contracted states (Chapter 3), while in children with CP the thickness of only the RA differed significantly from its resting state suggesting poor recruitment of these muscles in providing stability to the trunk during this activity. It could however also be postulated that these muscles may already have been in a contracted state as seen by the thicker baseline measurements recorded in the supine position so that the difference recorded during the head-up activity was smaller. Potential range of shortening was investigated in the current study by examining the interaction between children with TD and with CP with regard to thickness measures during rest and contracted state. These results suggest that children with CP may have reduced potential range for contraction however it is not clear whether this is due to morphological changes, underlying spasticity or biomechanical alignment.

No significant difference for the percentage change calculated in the TrA muscle between children with TD and STCP was found. Whether this is typically an indication of poor recruitment of the TrA muscle during activity in all children less than 13 years old still needs to be determined.

A significant difference was recorded for percentage change in the OE muscle in both groups of children. However, this muscle was thinner in the contracted state, suggesting that it was either stretched or compressed during the head lift activity. Although it is possible for a muscle to be active while being stretched – as is seen during eccentric type muscle activity⁶⁸ – it is unknown if there was activity in these muscles. Repeated studies using EMG would indicate if this were so.

As can be seen from the large standard deviations, considerable variation between individuals in both groups was seen when the percentage change during contraction was calculated. Although there was a significant difference between children with TD

and CP, the relatively small percentage change observed in the TrA and OI muscles in both groups suggest that for the head-up activity in children these trunk stabilisers are poorly recruited when compared to the larger percentage change seen in the RA muscle during the same activity. The association however between percentage change and activity warrants some discussion in that it is argued that for effective stabilising function very low levels of activity should occur within stabiliser muscles to allow for sustained contraction over extended periods of time. In the supine position, the body is fully supported and while lifting the head disturbs the centre of gravity, it may not be enough to demand greater activity in the deeper stabiliser muscles.

Responsiveness of US imaging in detecting these low levels of contraction could also be questioned, even more so in children who present with substantially thinner muscles than adults. Hodges and colleagues have demonstrated that the responsiveness of ultrasound imaging in detecting EMG levels of activity is less for the abdominal muscles than for that recorded in limb musculature. In adults US imaging was sensitive enough to reliably detect contractions of 12% MVC in TrA and 22% MVC in OI. These relationships have not yet been investigated in children. Furthermore without normative values it is difficult to interpret findings in children with STCP. Although the smallest real difference (SRD) (refer to 3.4.3) calculated for children to represent real change applies to repeated measures under identical circumstances (i.e. resting measure 1 vs. resting measure 2) these values suggest that US imaging may not be responsive enough to detect change in lower levels of activity in the TrA muscle.

4.5.4 Standing abdominal muscle thickness measurements in children with STCP

Although the abdominal muscles may be recruited during stance in order to maintain upright posture²⁶⁵ it was hypothesised that the thickness measurements of all four abdominal muscles would still be thinner in standing than in supine as in this position spinal alignment would be different. Although no comparison was made, it was assumed that in children with CP who commonly present with an exaggerate anterior pelvic tilt in standing⁸⁷ the difference between supine and standing would be significant. While the thickness measurements of three of the four abdominal muscles were significantly thinner in the standing position, the thickness of the RA muscle remained unchanged. If, as hypothesised, the excessive anterior pelvic tilt and increased lumbar

lordosis did stretch all four abdominal muscles, it could be assumed that either compensatory thoracic flexion accounts for the unchanged measurement in the RA (as it is attached to the lower ribs and costal cartilages) or as children in the current study were allowed to touch/or hold onto the railings of parallel bars, slight flexion of the upper quadrant was encouraged. Posturography and / or motion analysis during the leg lift activity is recommended

Although there is currently no evidence that increasing load correlates with an increase in thickness in these muscles, it was also hypothesised that in the standing position because of increased demand on the trunk musculature compared to that experienced in the supine position, lifting one leg would result in greater abdominal contraction and that the measurements of thickness recorded in standing would be significantly thicker than that recorded in supine. Although in standing some contraction of the abdominal muscles in order to maintain upright stance could be expected (see above), calculation of the percentage change between resting and contracted states corroborate this assumption in three of the four muscles. The TrA, OE and RA muscles were significantly thicker, while no differences between the two positions for the resting measures were found for the OI muscle. It could be hypothesised that during bilateral stance the OI muscle is active (presumably for the maintenance of upright stance) which offsets/counterbalances the thinning that occurred due to being biomechanically stretched.

While activity in the abdominal muscles is not necessary to enable standing, more upright posture demands increased activity in all stabilisers of the trunk including co-contraction of the deeper fibres of the gluteus maximus muscle³⁶⁰. While all children in the current study could stand independently, not all children were able to lift their leg without additional support. While bilateral stance assists the pelvis in maintaining a relatively stable position in terms of lateral tilt, the concurrent contraction in the hip extensors provides stability to the pelvis in terms of anterior-posterior tilt. As some children with CP move into a unilateral stance position, the weak hip abductors result in a drop of the pelvis and as such the ability of the abdominal muscles to contract is further affected. The children were allowed to use the parallel bars for support which provided a more stable base at the shoulders. This ensured a more stable thoracic wall which then provided a point of fixation from which the abdominal muscles could contract and lifting the leg was possible. Albeit that the change in thickness recorded in the current study suggests that the abdominal muscles are weak in children with STCP,

inclusion of data pertaining to lower limb strength profiles, especially related to the hip musculature is recommended when investigating abdominal muscle activity.

4.5.5 Clinical relevance of abdominal muscle thickness measurements in children

4.5.5.1 *Resting thickness measurements*

The current study provides evidence that there were structural / size differences in abdominal muscle architecture between the two groups of children. The thicker muscles in children with STCP suggest that either these muscles are more active than in children with TD - and if it were possible to isolate activity in each muscle, it may therefore be that children with CP have stronger muscles than those for age-matched TD peers – or architectural changes due to hypertonia and or spasticity resulted in pseudo-hypertrophy. Similarly ‘more’ affected muscles were thicker than less or unaffected muscles in children with STCP. The weaker torque production however seen in children with STCP suggests that the architectural and biomechanical differences affecting the ability to recruit these muscles are more likely more influential contributing factors to lower limb dysfunction. The study suggests that posture and change in position may affect the resting thickness of the abdominal muscles.

4.5.5.2 *Thickness measurements recorded during activity*

Although considerable variation occurred between individuals for percentage change - which ranged from -40% for the IO muscle in the supine position to +108.7% for the TrA in the standing position - the results confirm that each of the four abdominal muscles can contract in order to contribute toward stabilising the trunk, but that recruitment is dependent on the load and position of the trunk. The pattern of recruitment differs between children with TD and STCP in that children with CP recruit relevant muscles significantly less than their age-matched peers. In the current study these comparisons were only made with children lying in the supine position and only isometric activity was investigated. It is however presumed that similar, if not greater differences will be found when change in thickness is recorded during activity.

When investigating recruitment, the relative order of change in thickness as well as the accumulative effect should be calculated. A study by Anders et al. (2007) which

described RA, OI and OE activation patterns during walking at different speeds confirms involvement of these muscles in gait and concluded that although there are differences in individual muscle activation strategies for walking at different speeds, the increasing cumulative effect correlates with increasing walking speed¹²³. Total relative thickness was not investigated in the current study and whether these relationships between cumulative effect and walking speed exist in children remains to be established.

In adults symmetrical activity in the four abdominal muscles has been reported during activity of the limbs while the trunk is kept stationary^{351;359}. This symmetry was also noted in subjects with low back pain, irrespective of uni- or bilateral pain³⁶¹. This has not yet been explored in children with or without pathology. The differences however noted between the more and less or unaffected sides in children with STCP may also affect symmetry in relation to recruitment.

4.6 Limitations of the study

The following limitations in the current study were identified:

- Only children between six and thirteen years were investigated in the study and although the sample size was large enough to detect what was regarded as being a significant difference between the two groups of children, the current results merely provide preliminary baseline measures for children with TD. For the establishment of norms a more representative sample regarding demographic and anthropometric characteristics is needed³⁶². A larger sample size will also allow for further investigation into potential confounders such as level of activity and participation in sport.
- Although the sample size of the group of children with STCP was smaller than that of the group of children with TD, the groups did not differ significantly from one another in regards to height, weight and body mass index. Both groups also fell within normal to underweight growth curve values³⁶³ as children with a BMI of $>25\text{kg/m}^2$ were excluded. The stringent BMI criterion for inclusion in the current study did not allow for investigation into the effect of increased adipose tissue on abdominal muscle thickness measurements.

- Generalisability was further limited in that in the current study representation of the CP population was limited to GMFCS Levels I-III¹⁹⁹. According to Day et al. (2007) centiles of height and weight in children with CP are close to those of the general population for the highest functioning groups of CP. Although it is postulated that children with greater functional disability are also weaker, not all children in Level III presented with thinner abdominal muscle thickness measures than children in Levels I & II and vice versa.
- Only the spastic diplegic and spastic hemiplegic types of CP were investigated in the current study. However, whether diagnosis should be included as a 'category' or a variable, when investigating function is debateable. With the large variation in clinical presentation within the typical CP diagnosis, functional abilities such as postural control, balance or gait may be more determined by the functioning of specific muscles and systems (more impairment level) than by diagnosis. This argument is supported by the Executive Committee for the Definition of Cerebral Palsy (USA)¹ who in their endeavour to formulate a more appropriate definition and classification system for persons with cerebral palsy stated that diagnosis too should include more than body region involvement and type of motor disorder^{2;192}. It is recommended that the GMFCS be used to classify research participants instead of diagnosis.

4.7 Recommendations for future research

The following are recommendations related to further investigation into the role of the abdominal muscles in postural control:

- EMG studies to determine responsiveness of ultrasound imaging for detecting abdominal muscle activity in children.
- Establish norms for resting thickness measures and patterns of recruitment for selected activity. This is recommended for both isometric (stabiliser function) and isotonic (mover function) muscle functioning. Similarly activity on both sides should be investigated – while the abdominal stabilisers (TrA and IO) should function bilaterally, the influence of limb movement regarding speed and direction should be investigated. Knowledge of activity (level and relative order of recruitment) in

children with TD will allow for better understanding / more accurate interpretation of strategies used in children with CP.

- Larger sample sizes or more stringent inclusion criteria is recommended to allow for investigation into the influence of spinal and other orthopaedic deformities, dominance, level of activity and participation in sport.
- The relationship(s) between impairment in terms of resting abdominal muscle thickness measurements and patterns of recruitment and posture and lower limb function need to be determined.
- Wider investigation into abdominal muscle architecture to confirm hypotheses regarding causation of poorer abdominal muscle recruitment in children with STCP.

4.8 Conclusion

The current study provides preliminary baseline measurements for the resting thickness of all four abdominal muscles in children with TD and also for children with STCP. Children with motor problems have thicker muscles at rest than children with TD and there is some evidence that the more affected the child, the thicker the muscle. At this point the contribution of spasticity to muscle morphology is still unknown and needs further investigation. Ultrasound imaging of resting thickness measures may not be an appropriate outcome measure in children in that it is unclear whether the thicker resting muscles are indicative of increased resting 'contraction' or suggest increased ability to generate force.

This study has provided evidence that children with STCP can/do recruit these muscles during activity of the head and or limbs but the recruitment strategies differ to those seen in children with TD. The percentage change is less and it is unclear whether this is due to a resting state of contraction in children with STCP which diminishes the ability to generate additional force. It may also be due to the inability to adequately contract.

Whereas it is clear that children with CP do function more poorly than TD children, it is surprising that the muscle diameters, which can be taken to correlate with the cross sectional areas are either similar or even greater than in TD children. It would appear necessary to establish whether the muscle thickness is related to function in any way and this is examined in the following chapter.

The relationship between the abdominal muscles and pelvic tilt and functioning in children with spastic type cerebral palsy

4.1 Background

Although movement of the trunk may occur and assist in performance, for gait and many other functional activities the role of the abdominal muscles serve primarily to maintain upright posture while the limbs move and activity in all four abdominal muscles is required for energy efficient functioning⁷⁰. Despite considerable debate in the literature regarding the definition of core stability⁹⁶, there is evidence that a stable trunk – vertebral column, shoulder and or pelvic girdle - is an essential component for providing a stable base from which movement (especially co-ordinated movement) can occur⁷⁰. When the neuromuscular system however is not optimally efficient there is some evidence that suggests that uncoordinated muscular activity and weakness of particularly the local trunk stabilisers can result in impaired functioning^{78;116}. Weakness of the trunk associated with lower levels of functioning in the CP population may be responsible for the poor postural control seen in these children^{5;73;84;339}.

In cerebral palsy (CP) the either rigid or excessive truncal movement observed during functional activities is well described^{49;72;73} (refer to 2.4.3). Although it is hypothesised that the excessive co-activation present could be due to altered descending control of the central nervous system, it may also be due to compensation due to agonist weakness⁷³.

Results from the ultrasound (US) imaging reliability studies (Chapters 3 & 4) suggest that while children in the higher levels of functioning (Levels I,II and III) with CP can - when positioned in the supine and standing positions - recruit the abdominal muscles, differences were noted in the pattern of recruitment of these muscles between children with CP and children with typical development (TD). The results suggested that children with CP recruit the deeper stabilising abdominal muscles significantly less than their age-matched peers with TD during the same activity in that the percentage change from rest to head-up activity was generally significantly less than in children

with STCP. In both groups of children recruitment of the TrA muscle however was negligible during the same activity performed in the supine position.

While in children with TD significant correlation was found between resting thickness measures and age and body stature, in children with CP no clear relationships were found. Chapter 4 also raised the issue regarding the extent to which diagnosis; posture and functional ability are contributing factors to the differences found between children with CP and those with TD. It remains to be established whether the thickness of the abdominal muscle(s) (and therefore activity of these muscles) is related to function in any way and this is examined in the following study. A better understanding of these relationships could better inform (re)habilitation therapists regarding treatment strategies related to inclusion of trunk targeting intervention.

4.2 Aims and objectives

In a group of six to 13 year old ambulant children with spastic diplegia or hemiplegia, the specific objectives of the current study were to determine:

- if there is a relationship between measurements of impairments and functional ability i.e. is there a relationship between degree of pelvic tilt regarding antero-posterior (a-p) tilt, abdominal muscle strength (*as determined by the number of sit-ups executed in one minute*) and distance walked in one minute
- if there is a relationship between resting abdominal muscle thickness measurements (in supine and in the standing position) and functioning and impairment in that it could be assumed that children with poorer functional performance (*as determined by their classification according to the GMFCS levels*) will present with thicker muscles based on the findings in the previous chapter (Chapter 4)
- if there is a relationship between the change in thickness of the abdominal muscles recorded during sub-maximal activity (in supine and/or in standing) and functioning and impairment

Additional objectives:

If a significant independent correlation is found between muscle thickness measurements and impairment and functional activity, this study also aimed to determine which parameters are predictive of functional ability. The secondary objectives of the study were therefore to determine:

- which of the following parameters predict distance walked in one minute (*and degree of pelvic tilt*) ...
 - supine resting thickness of the four abdominal muscles
 - standing resting thickness of the four abdominal muscles
 - % change in thickness of the four muscles during the head-up activity in supine
 - % change in thickness of the four muscles during contra-lateral hip flexion in standing
 - number of sit-ups performed in one minute
 - BMI
 - age
 - gender and
 - GMFCS level and
 - degree of pelvic tilt (*and distance walked in one minute*)

5.3 Methodology

5.3.1 Study design

As this study aimed to determine the relationship between several variables i.e. abdominal muscle thickness measurements, abdominal muscle strength, the position of the pelvis and gait speed in a particular sample i.e. primary school children with STCP, a descriptive, cross sectional, correlation study design was utilized (Figure 14). Thicknesses of the four abdominal muscles recorded in the supine and standing positions were compared to the strength of the abdominal muscles and the position of the pelvis in terms of anterior and posterior pelvic tilt. Thickness measurements were also compared to the distance walked in one minute during self-selected fast walking. The relationship between pelvic tilt and fast walking was also investigated.

5.3.1 Subjects and sampling

All six to 13 year old ambulant children – with or without walking aids, with or without orthoses – diagnosed with spastic type diplegic or hemiplegic cerebral palsy were eligible for participation in the current study.

The sampling frame included all children attending a local school for learners with special education needs who were members of the population described above. These children, who were identified by the physiotherapists from the participating school were listed and given code numbers. Thirty potential participants were randomly selected and invited to participate in the study. Following telephonic contact with the parent or legal guardian, information leaflets were sent home. Written informed consent was obtained from the parent or legal guardian (Appendix 3) as well as assent from the participant (Appendix 4).

Inclusion criteria

To be included in the study, subjects had to meet the following criteria:

- be diagnosed by a paediatrician as having spastic type diplegic or hemiplegic cerebral palsy
- be between the ages of six and 13 years
- be in good general health
- be ambulant - with or without walking aids, with or without orthoses (i.e. Gross Motor Function Classification Scale (GMFCS) level I, II or III) as classified by the researcher
- be able to comprehend instructions in either English or Afrikaans

Exclusion criteria

Subjects were excluded from the study if:

- they presented with any other dysfunction or condition affecting motor performance (e.g. ataxia, spina bifida, muscular dystrophy etc.)
- had any orthopaedic surgery or spasticity altering procedures in the previous 12 months
- had a body mass index (BMI) $> 25\text{kg/m}^2$ (too much adipose tissue renders ultrasound imaging difficult and effects reliability³⁶⁴ (Chapter 3))

In the current study it was envisaged to analyse data using regression analysis in order to investigate relationships between variables. Although the literature suggests that there should be approximately ten cases for each variable entered into a regression analysis³⁶⁵, the pool of subjects was limited and to the researcher's knowledge, almost all eligible children in the participating school were entered into the study.

5.3.2 Procedure

Approval was obtained from the Research Ethics Committee at Stellenbosch University^{xiii} (N09/08/201), the Research Directorate from the Department of Education as well as the Headmaster of the participating school. The names of all 30 eligible participants who met the inclusion criteria, were identified by physiotherapists from the participating school and invited either telephonically or via an information leaflet to participate in the current study. Written informed consent was obtained from either the parent(s) or legal guardian from those who agreed to take part (Appendix 3). Participants were also asked to assent to participation in the study (Appendix 4).

5.3.2.1 Instrumentation

Ultrasound imaging, the 1-Minute Walk Test and 2-D photographic imaging for posture analysis was used to assess abdominal muscle thickness during rest in supine and in standing, distance walked in one minute and posture in standing. The total number of sit-ups in one minute was also recorded to measure abdominal muscle strength. As participants in the current study were being subjected to extensive testing the instruments / outcome measures were selected on the basis that they were cost effective, portable, and minimal to non-invasive.

Measurement of anthropometric characteristics

Baseline demographic variables - age and level of functioning according to the Gross Motor Function Classification Scale (GMFCS)⁵, use of walking aids and or orthoses -

^{xiii} As the researcher is a staff member at Stellenbosch University in order to facilitate management of the MRC funding for the project, the study was registered and approved at both US and UCT. Approval was sought for this phase of the study from US only to expedite the research process.

were recorded and entered into an Excel spread sheet. Height was measured using a standard tape measure fixed to a wall. Without shoes, children stood with their backs to the wall and asked to stand as upright as possible. In cases where participants were unable to stand with extended knees, the tester passively pushed the knees into extension to ensure actual height measurement and not apparent height due to crouch posture. A metal ruler was placed on the vertex of the skull parallel with the floor to determine the height measurement. Weight was measured using a calibrated digital SALTER Personal Fitness Plus Scale (UK) (model 9191). Participants were asked to undress down to shorts/skirts and vests before being weighed.

Ultrasound imaging (US)

The thickness of each of the four abdominal muscles - TrA, OI, OE and the RA - were recorded and measured, using a Siemens® Accusonic X150 ultrasound imaging machine with a 5.5cm wide band linear array frequency of 5Hz. B-mode (2-D). Real-time images of the four abdominal muscles were captured. Images were recorded on the right side in children with diplegia and the affected sides in children with hemiplegia. Inter- and intra-tester reliability of US imaging in the measurement of abdominal muscle thickness at rest in children with TD as well as in children with CP has been established (Chapter 3).

The 1-minute Walk Test

The fast one minute walk test as described by McDowell et al. (2005) is considered a valid descriptor of functional ability. This test has shown good correlation with both GMFM -88 ($r=0.92$) and GMFM -66 ($r=0.89$) with similar correlation for the dimensions D (standing) and E (walking, running and hopping)²⁷³. The test has also been shown to have a significant moderate relationship with energy efficiency of gait using a five minute O²-cost protocol²⁷⁴. The authors advocated the use of this measurement for its clinical feasibility in the absence of a gold standard measurement such as a 3D motion analysis system.

Digital Photographic 2D imaging for postural analysis

A high speed digital camera (Canon 40D) was used to capture static standing posture as viewed from the side. Images were downloaded to a personal computer (PC) and using Image J software (<http://rsbweb.nih.gov/ij/download.html>) the degree of antero-posterior pelvic tilt was measured. This software allows lines to be drawn or

superimposed onto the digital photographs. From these lines distance can be calibrated and calculated and similarly angles can be determined. Although the information obtained using 2D analysis is limited, stringent standardisation of the procedure can produce reliable measurements to determine kinematic variables^{366;367}.

Sit-ups in 1-minute

The total number of sit-ups executed in one minute was selected as a proxy of abdominal muscle strength and endurance (refer to 2.6.2.2). Although not a standardised outcome measure, this field performance test is used in research to reflect possible strength gains in the abdominal musculature³⁰³.

5.3.2.2 Location

A small private therapy room in the Physiotherapy Department was temporarily equipped with a plinth and used for data collection regarding the abdominal muscle strength and thickness measurements. A larger room was used to test balance and the school's gymnasium was used to assess gait function. Participants were tested during school hours and participants from the same class accompanied each other during the testing sessions.

5.3.2.3 Pilot study and reliability testing

Reliability for US imaging and abdominal muscle thickness measurements were determined in an earlier study (Chapter 3). To determine reliability of the tester for the 1-minute Walk Test; number of sit-ups executed in one minute and the measurement of the a-p angle (pelvic tilt) from a standing 2-D photographic image, repeated measurements by the same tester either on the same day or between days was conducted as described in the testing procedures below for each test. Intra-class correlation coefficients (ICC) (Statistica) were used to determine agreement between the two measurements (refer to 3.3.5). Table 25 shows acceptable ICC values i.e. intra-tester reliability for these measurements which were then all used in this study. It was deemed adequate to determine only the intra-tester reliability as for this correlation study only one test was to be conducted. It was furthermore envisaged that the same test and outcome measurements would be utilized in the intervention study (Chapter 6) where the same tester would conduct the pre and post measurements for each test or outcome measure.

Table 25 Intra-tester reliability of outcome measurements: distance walked in 1min, no. of sit-ups in 1min and degree of pelvic tilt (2D-imaging) (Intraclass Correlations Coefficients) (n=14)

Outcome measurement	ICC	95% Confidence Interval	SEM
1-min walk test (m)	0.979	0.910 ; 0.994	2.403
no. of sit-ups in 1min	0.990	0.972 ; 0.997	1.085
degree of a-p pelvic tilt (°)	0.982	0.939 ; 0.994	0.749

A pilot trial using older children or children not selected for participation in the current study was simultaneously conducted to determine and or refine testing procedures. Procedures, as described in the literature for each outcome were followed. Minor amendments were necessary and the procedures as described below were ultimately followed in the current study.

5.3.2.4 Testing procedure

All the measurements were taken at the school during school hours. Tests were conducted on one day in no specific order. The primary investigator conducted the one minute fast walking test and photographic imaging for posture analysis. A research assistant^{xiv} conducted the US imaging and measurements, and recorded the sit-ups executed in one minute.

Ultrasound imaging (US)

Subjects were first positioned in supine with their arms resting along their sides on a plinth with their knees supported on a cushion. The second set of images was captured while in a standing position between parallel bars. Participants were instructed to place their hands on the bars and to touch lightly. The same procedure as described in Chapter 4 (refer to 4.3.4.3) was used in the current study. For both positions, a resting image was captured on end-inspiration as observed by the tester. In the supine position, the second measurement required a sub-maximal contraction whereby participants were instructed to tuck in the chin and lift their head. In standing the second image was captured during contra-lateral leg lift (flexing the hip and knee to

^{xiv} NDT trained physiotherapist not employed by the school

90°). Images were captured for the right side only in children with diplegia while in children with hemiplegia, the affected side was captured.

The 1-minute Walk Test

For this measurement, participants were asked to walk as fast as they can on a marked oval level course for exactly one minute. The distance covered was recorded. Participants using splints and or walking aids were permitted to use them during this test. A trial run is recommended²⁸⁹ and was done with a 5 – 10min rest before the main trial commenced.

2D-Photographic Posture Analysis

Wearing only under garments, eight reflective markers (from the VICON Motion Analysis System) were placed on the following bony points (Figure 15):

- C6
- the superior border of the manubrium
- mid-point on the lateral border of the acromion
- posterior superior iliac spine (PSIS)
- anterior superior iliac spine (ASIS)
- the sacrum
- greater trochanter
- lateral epicondyle
- lateral malleolus
- head of the 5th meta-tarsal bone

One photograph of each participant was taken. They were asked to stand as upright as possible and a lateral image, from the right only or in children with left-sided hemiplegia, from the left only, was captured. Images were downloaded onto a PC for analysis later. The image captured allowed for the measurement of several variables (angles and height measurements) related to posture. As the current study objectives were to investigate the relationship between the abdominal muscles and position of the pelvis, only the pelvic tilt (Figure 15) was computed and analysed in this study.



Figure 15 The lateral standing photographic image (anterior posterior pelvic tilt)

To ensure repeatability of the measurement:

- the camera was mounted on a tripod 130cm from the ground and
- positioned exactly 2.5m away from the opposite wall
- the camera was positioned to capture portrait style photographs
- and the settings recorded to be repeated at each measurement session
- markings on the wall at 50cm, 100cm and 150cm, 500cm wide formed a frame in which the children were positioned
- subjects stood with one foot on each side of a line 30cm from and parallel to the wall (Figure 13)
- subjects were asked to stand as upright as possible, look straight ahead
- no physical or verbal posture correction was done
- for subjects requiring support in standing, one hand on the wall was permitted

Sit-ups in 1-minute

In the crook lying position with the feet supported, subjects had to sit-up or curl-up to 90° hip flexion without arm support and return to the almost flat (flat hand) supine position as many times as they could in one minute.

5.3.3 Measurement and Data Processing

The data for each outcome measurement was processed as follows and entered into an Excel spread sheet for statistical analysis:

5.3.3.1 US imaging

Machine cursors were used to measure muscle thickness in millimetres (mm) within the fascia boundaries. The same procedure for measurement as described by Ferreira et al. (2004)⁷⁸ and used in Chapters 3 and 4 was utilised.

5.3.3.2 1-Minute Walk Test

The distance covered during the final 'round' was recorded in meters.

5.3.3.3 2D-Photographic Posture Analysis

All images were downloaded onto a personal computer (PC). Using Image J software, from the image captured in standing the antero-posterior pelvic tilt – the angle between a line drawn from the posterior superior iliac spine (PSIS) through the anterior superior iliac spine (ASIS); and a line from the PSIS parallel to the floor (Figure 15) - was determined. For the pelvic tilt measurement, the smaller the angle the more neutral the pelvis is positioned and a negative value suggests a posterior pelvic tilt.

5.3.3.4 Sit-ups in 1-minute

In the sport sector the findings of a study by Tse et al. (2010) found that a minor lumbar kyphosis can relatively lower muscle activity of the trunk flexor muscles³⁶⁸. For this reason the typical straight supine positioning was adapted and subjects in the current study were positioned in supine with the hips and knees in 65-70% flexion. The pelvis is stabilised by manually providing support by the therapist holding onto the child's knees. This position allows for a more stable base from which the abdominal muscles, now also placed in a physiologically more advantageous position, can function. Children therefore despite differences in posture regarding degree of pelvic tilt, have 'equal opportunity' to execute the activity. The total number of sit-ups executed in one minute was recorded.

5.3.4 Statistical analysis

Statistica (Version 9) was used to analyse data. Shapiro-Wilks tests were done to inspect distribution of the values of all the variables measured. Results from the previous ultrasound imaging studies (Chapters 3& 4) suggest some difference exists for the OI muscle between six to 13 years old boys and girls regarding thickness measurements and this parameter/variable was therefore further investigated in the current study. Similarly it was suggested that the level of functioning (according to the GMFCS) may be associated with abdominal muscle thickness measurements and was also investigated.

Pearson's correlations were used to investigate the relationships between GMFCS levels, impairment and functional ability – degree of a-p pelvic tilt, number of sit-ups and distance walked. A 5% significance level ($p < 0.05$) was used as guideline for determining significant differences.

One way ANOVA was used to investigate relationships between muscle thickness measurements and levels of functioning ability. Fisher least significant difference (LSD) post-hoc tests were done to inspect the data further and to determine the level of significance between the three levels (GMFCS Levels I, II and III). A 5% significance level ($p < 0.05$) was used as guideline for determining significant differences.

It was deemed appropriate to further inspect the relationships between various demographic and anthropometric-, posture- and gait variables. All subset regression analysis was done to determine which variables are predictive of distance walked in one minute and which were predictive of degree of antero-posterior pelvic tilt. Due to the small sample size a maximum of five variables to be included in the final model was set. Furthermore when variables correlated with more than 0.7, only one variable was selected for inclusion. R^2 values were then further inspected in order to determine the most relevant model.

5.3.5 Ethical considerations

The basic ethical principles of respect, autonomy, justice, beneficence and non-maleficence were addressed as follows:

Permission was sought from the Research Ethics Committee at Stellenbosch University and from Western Cape Education Department to conduct the study at the school. Informed consent was obtained from parents and or legal guardians of all potential participants and informed assent from all those participants was sought. Participation was entirely voluntary and refusal or discontinuation did not affect standard treatment. Children and parents had the right to withdraw at any time without it affecting current therapy management at the school. All therapy was continued as per usual.

Anonymity and confidentiality was assured to all participants. All personal information would be used solely by the research staff and should there be any publications, the participant's identity will not be disclosed. Consent to use any photographs taken during testing or participation in any presentations or publications will be separately obtained from parents and participants – faces of the children will be made unrecognizable and parents or legal guardian and the child will be asked to sign the back of the photograph if they both agreed to the use thereof. Photographs not selected for publication or academic presentation purposes will be destroyed following completion of the main study.

Although children selected for participation in the current study come from disadvantaged backgrounds, no direct or potential benefit was expected by participating in the current study. Potential risk was disclosed or discussed with both children and parents, although no harm or injury was envisaged due to the non-invasive nature of all the outcomes or tests selected. The results will be made available to the therapists at Eros School, and to the parents upon request. In case of accidental injury during testing, a registered nurse or doctor was available at the school.

5.4 Results

Description of the sample's demographic characteristics, anthropometric- and outcome variable measurements will precede a report of the findings of the correlation analysis regarding the relationship(s) between abdominal muscle thickness measurements and degree of pelvic tilt, the number of sit-ups and distance walked in one minute. Whether the level of classification (i.e. GMFCS Levels I, II & III) of the current sample was a valid indicator of functional ability, was also investigated.

5.4.1 Descriptive characteristics

5.4.1.1 Demographic and anthropometric measurements

Thirty informed consent forms were handed out to learners at the participating school and 27 subjects were ultimately recruited into the study (Figure 16). The parents of three potential subjects did not consent to participation. There were 17 males and ten females enrolled. Fifteen subjects were diagnosed with spastic diplegia, nine presented with right hemiplegia and three subjects with left hemiplegia. Seventy eight percent of the sample was independently ambulant while six participants required wheelchairs for (longer) distance ambulation (Table 26).

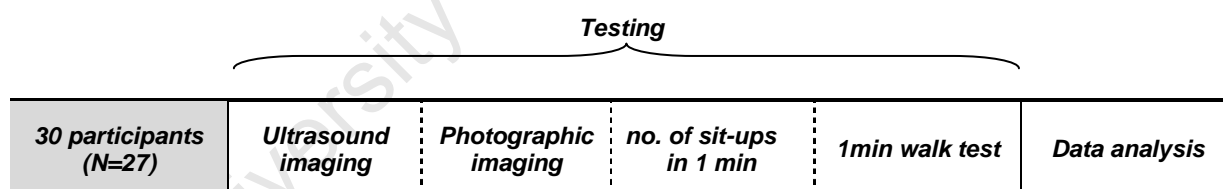


Figure 16 Participant recruitment and procedure

Table 26 Description of level of functioning and use of orthoses and walking aids

GMFCS I	13
II	8
III	6
single AFO	1
bilateral AFO's	1
crutches	1
rollator/K-walker	3

Not all the values recorded for demographic characteristics and anthropometric measurements were found to be normally distributed. The values for age of the current sample (Table 27) ranged from 7.3 to 13.8 years (median = 12.1 years) while height ranged from 1.16 to 1.57m (median = 1.4m). Subgroup analysis (Mann Whitney-U test) was also conducted to compare the group with hemiplegia with the group with diplegia for all demographic variables and no significant difference between the groups for any of the variables was found. Similarly no significant differences were found between boys and girls for any of these variables.

Table 27 Descriptive statistics for age, height, weight and BMI (n=27)

	Mean	SD	Norm (SW)	Norm p
age (yrs)	11.4	1.95	0.918	0.035*
height (m)	1.4	0.11	0.922	0.044*
weight (kg)	33.2	7.37	0.978	0.815
BMI (kg/m ²)	16.5	2.73	0.949	0.206

Norm = normality; SW = Shapiro-Wilks, * $p < 0.05$

5.4.1.2 Impairment and functional measurements

Values for the measurement of a-p pelvic tilt and distance walked in one minute were normally distributed (Table 28). The number of sit-ups executed in one minute by the current sample varied from 0 to 32 sit-ups (median = 12 sit-ups).

Table 28 Descriptive statistics for measurements of impairment and functional ability (n=27)

outcome	Mean	SD	Norm (SW)	Norm p
standing pelvic tilt (°)	20.0°	6.1	0.95	0.222
distance (m)	92.6m	23.9	0.96	0.283
no. of sit-ups	12.7	11.2	0.88	0.006*

Norm = normality; SW = Shapiro-Wilks, * $p < 0.05$

5.4.1.3 Muscle thickness measurements

The average thicknesses of all four the abdominal muscles are reported in Table 29. Although all four muscles were thinner in the standing position, the same pattern of relative descending order of thickness was seen in both positions i.e. TrA<OE<RA<OI. Except for the resting thickness of the OI muscle in the standing position, the values for all thickness measurements were normally distributed (Table 29). The thickness of the OI muscle in standing ranged from 2.7 to 11.9mm (median = 5.5mm).

Table 29 Descriptive statistics for resting abdominal muscle thickness measurements (mm) (n=27)

resting muscle thickness		Mean (mm)	SD	Norm (SW)	Norm p
supine	TrA	2.68	0.65	0.96	0.392
	OE	3.88	1.23	0.97	0.536
	OI	6.40	1.45	0.96	0.349
	RA	6.00	1.11	0.98	0.751
standing	TrA	2.33	0.56	0.98	0.912
	OE	3.22	0.97	0.96	0.318
	OI	5.67	2.17	0.90	0.015*
	RA	5.47	1.25	0.96	0.308

Norm = normality; SW = Shapiro-Wilks, * $p < 0.05$

The mean percentage change that occurred during activity in each of the four abdominal muscles is reported in Table 30. The values of the measurements recorded in supine were all normally distributed. This was not the case for measurements recorded during the leg lift activity in the standing position (Table 30). The range and median for these measurements for all four abdominal muscles is shown in Table 31. In the supine position only the RA muscle showed an average increase in thickness during the head-up activity, while in standing TrA, OI and RA muscles showed an increase in thickness (Table 31). The large variation in recruitment during the leg lift activity in standing can be seen in the graph below (Figure 17).

Table 30 Descriptive statistics for percentage change in muscle thickness during activity (%) (n=27)

% change in muscle thickness		Mean (mm)	SD	Norm (SW)	Norm p
supine (during head-up)	TrA	-1.47	17.62	0.97	0.679
	OI	-1.86	19.05	0.98	0.829
	OE	-7.40	17.56	0.93	0.087
	RA	34.40	21.30	0.96	0.290
standing (during leg lift)	TrA	25.07	29.77	0.89	0.008*
	OI	12.02	24.31	0.89	0.009*
	OE	2.81	26.57	0.85	0.001*
	RA	3.06	11.35	0.81	0.000*

Norm = normality; SW = Shapiro-Wilks, * $p < 0.05$

Table 31 Descriptive statistics for the measurements of percentage change during contra-lateral leg lift in standing (%) (n=27)

% change in muscle thickness		Med (%)	Min (%)	Max (%)
Standing	TrA	23.7	-17.7	108.8
	OI	10.0	-23.6	84.3
	OE	-1.6	-43.9	100.0
	RA	1.0	-14.0	36.6

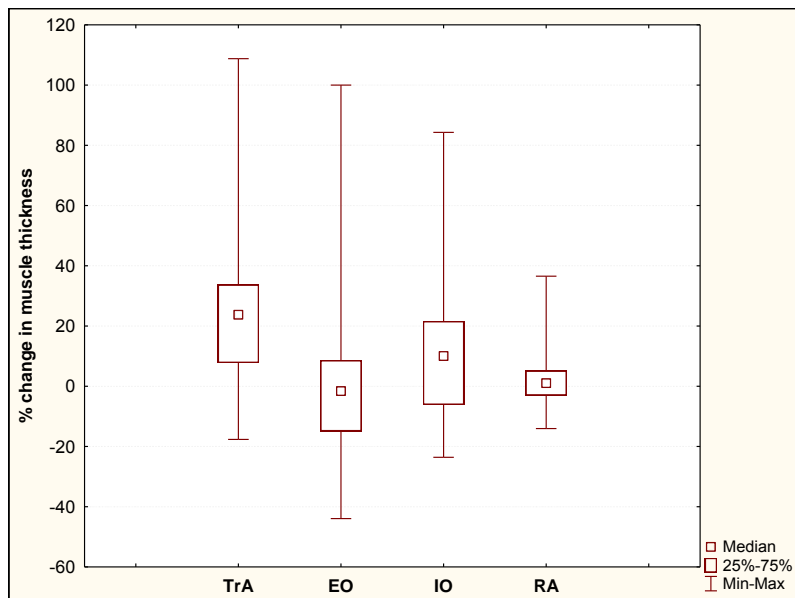


Figure 17 Descriptive statistics for the measurements of percentage change during contra-lateral leg lift in standing (%) (n=27)

5.4.2 Correlations between measurements of impairments and functional ability

Significant correlations were found between GMFCS Levels I-III and degree of a-p pelvic tilt, distance walked in one minute and strength of the abdominal muscles (as determined by the number of sit-ups performed in one minute) (Table 32), suggesting that the children in the current study were correctly classified in terms of functional ability.

Table 32 Correlations between GMFCS Levels I-III and impairment and functional ability (n=27)

	pelvic tilt (°)	distance (m)	no of sit-ups in 1 min
GMFCS	<i>r= 0.37</i> <i>p= 0.050</i>	<i>r= -0.58</i> <i>p= 0.001</i>	<i>r= -0.50</i> <i>p= 0.008</i>

A significant inverse correlation was found between degree of pelvic tilt regarding antero-posterior tilt and abdominal muscle strength (as determined by the number of sit-ups executed in one minute) suggesting that the greater the degree of tilt, the weaker the abdominal muscles are. In addition, an increased pelvic tilt was correlated

with a shorter distance walked in one minute. An increased number of sit-ups was correlated with a greater distance walked (Table 33).

Table 33 Correlations between a-p pelvic tilt, abdominal muscle strength and gait (n=27)

	pelvic tilt (°)	distance (m)
distance (m)	$r = -0.38$ $p = 0.050$	
no of sit-ups in 1 min	$r = -0.54$ $p = 0.004$	$r = 0.58$ $p = 0.002$

Large variation was found between participants. Not all children classified at a lower level presented with weaker abdominal muscles. Two participants in Level III were able to execute 5 and 18 sit-ups respectively (median = 12 sit-ups), while three participants in Level II and one participant in Level I were unable to execute any sit-ups at all. Except for one individual (GMFCS Level I) all of the above participants presented with poorer gait function in that they covered less distance than the mean for the group (<90m).

5.4.3 Correlations between abdominal muscle thickness measurements and functioning and impairment

As the GMFCS levels of the sample in the current study correlated with impairment (pelvic tilt) and functional ability (distance walked and number of sit-ups in one minute) (refer to 5.4.2) it was deemed appropriate to investigate the relationship between the different muscle thickness and GMFCS levels rather than investigate the relationship between walking, sit-ups and pelvic tilt. This reduced the number of calculations required and clarified whether any relationships existed between abdominal muscle thickness and function.

5.4.3.1 Muscle thickness as measured in the supine position

One way ANOVA suggest that no significant differences exist between the different classification levels of functioning and resting thickness measurements for any of the four abdominal muscles recorded in the supine position (Figures 18A -21A). Similarly, no significant differences were found between the different classification levels of

functioning and for the percentage change which occurred during the head-up activity in the supine position for any of the four abdominal muscles (Figures 18B- 21B). Although there was no pattern in terms of muscle thickness, children performing at Level I all demonstrated the greatest percentage change from resting to head up (apart from OE).

As noted in Chapter 4, the percentage change was much higher in the RA muscle compared to the other muscles and the only muscle that was consistently thicker during contraction / activity than that recorded at rest. In the other three abdominal muscles (TrA, OI and OE) a negative change was seen in several cases suggesting that for these participants the muscle at rest was thicker than during the activity.

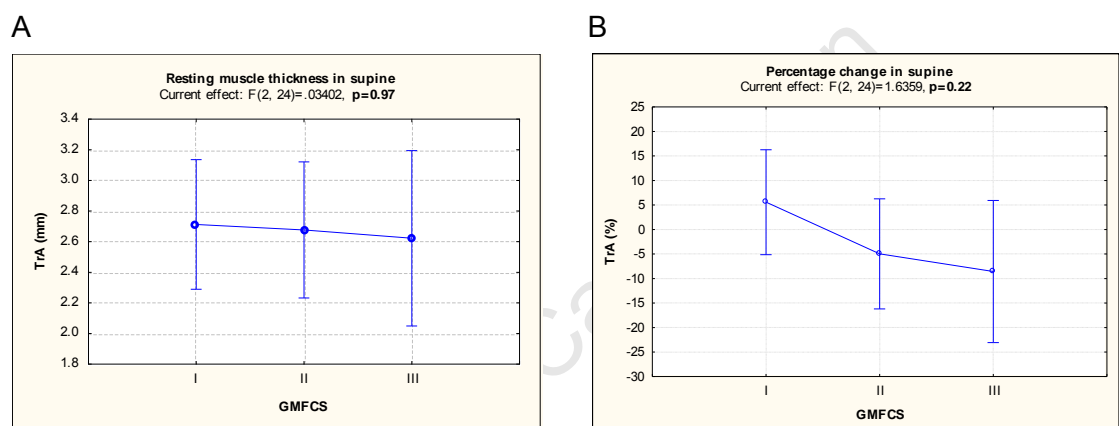


Figure 18A: Comparison of resting TrA muscle thickness measurements in supine and level of functioning; **18 B:** Comparison of % change during head-up activity of the TrA muscle and level of functioning

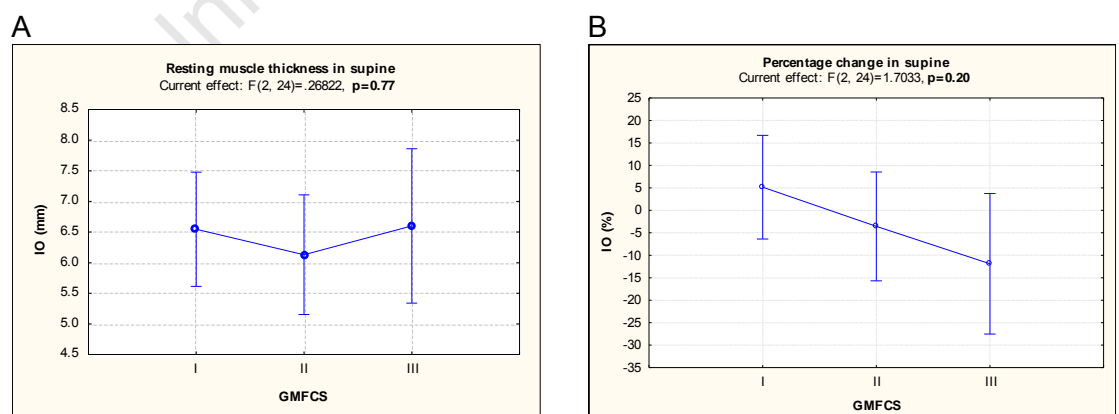


Figure 19 A: Comparison of resting OI muscle thickness measurements in supine and level of functioning; **19 B:** Comparison of % change during head-up activity of the OI muscle and level of functioning

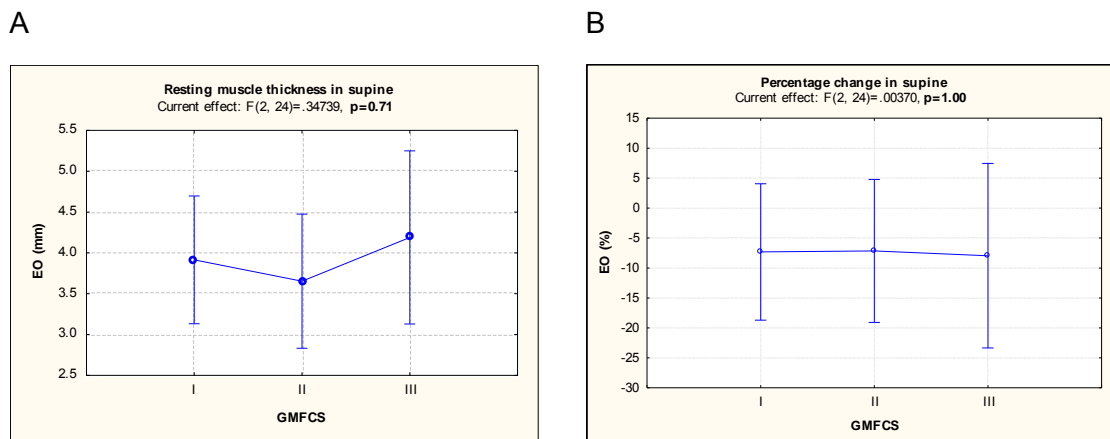


Figure 20 A: Comparison of resting OE muscle thickness measurements in supine and level of functioning; **20 B:** Comparison of % change during head-up activity of the OE muscle and level of functioning

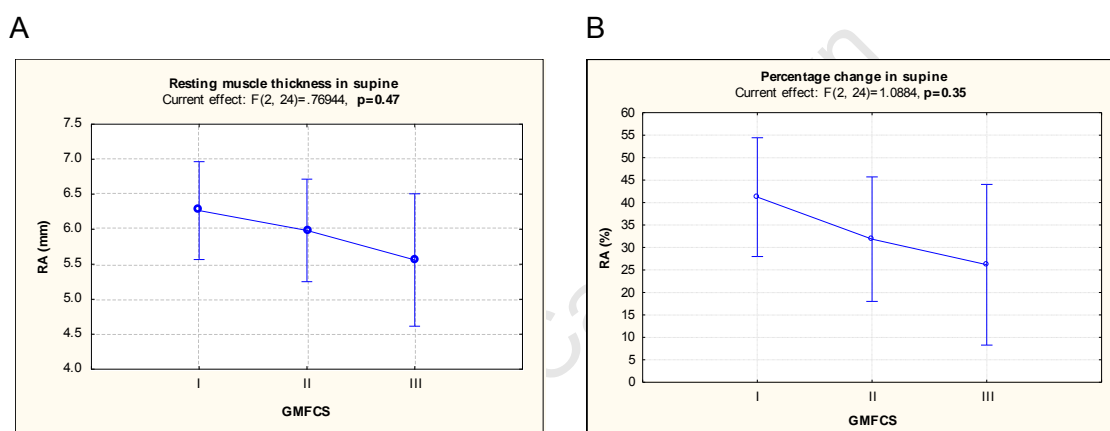


Figure 21 A: Comparison of resting RA muscle thickness measurements in supine and level of functioning; **21 B:** Comparison of % change during head-up activity of the RA muscle and level of functioning

5.4.3.2 Muscle thickness as measured in the standing position

One way ANOVA suggest that no significant differences exist between the different classification levels of functioning and resting thickness measurements recorded in the standing position for any of the four abdominal muscles (Figures 22A-25B).

No significant differences were found between the different classification levels of functioning and the percentage change which occurred during the contra-lateral leg lift activity in the standing position for three of the four abdominal muscles (Figure 22B, 23B and 25B). For the OE muscle however children classified as level III had significantly higher percentage change in thickness recorded during this activity than

children classified as level II ($p=0.02$) or Level I ($p=0.03$) (as indicated by significant letters in Figure 15B).

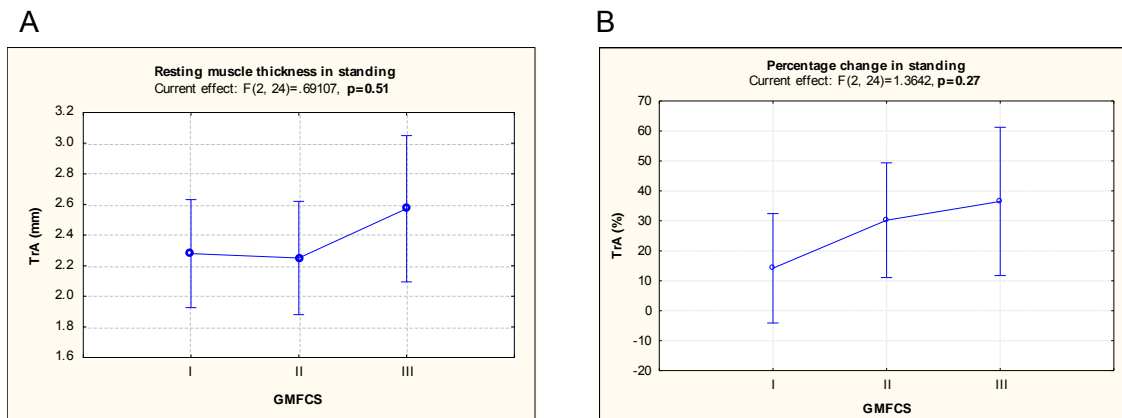


Figure 22 A: Comparison of resting TrA muscle thickness measurements in standing and level of functioning; **22 B:** Comparison of % change during contra-lateral leg lift activity of the TrA muscle and level of functioning

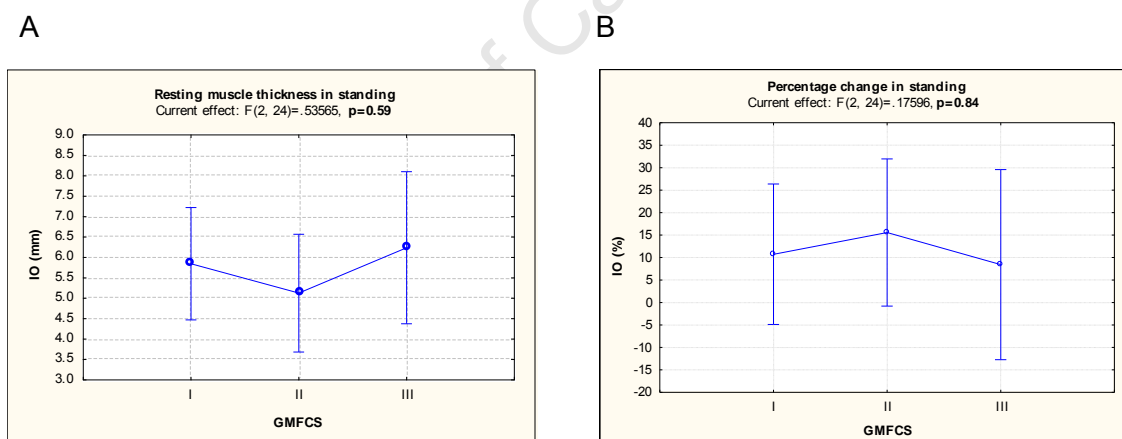


Figure 23 A: Comparison of resting OI muscle thickness measurements in standing and level of functioning; **23 B:** Comparison of % change during contra-lateral leg lift activity of the OI muscle and level of functioning

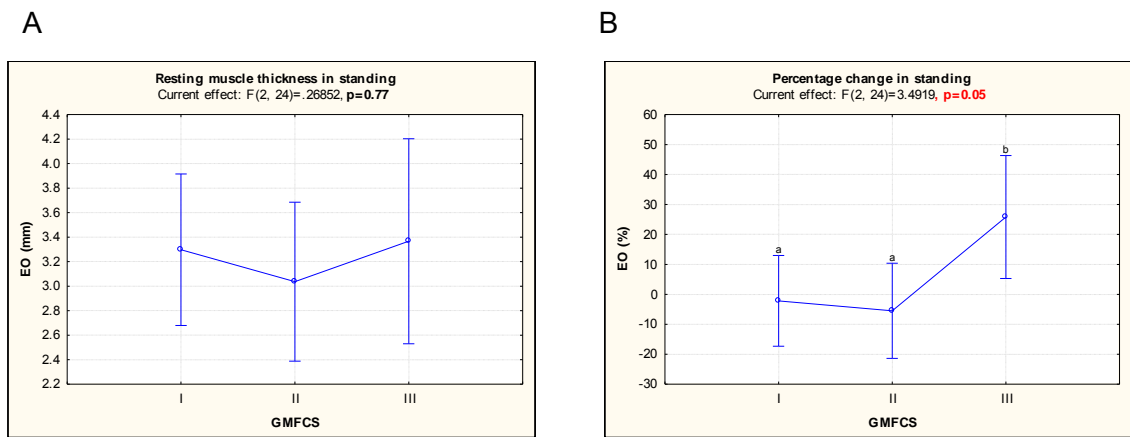


Figure 24 A: Comparison of resting OE muscle thickness measurements in standing and level of functioning; **24 B:** Comparison of % change during contra-lateral leg lift activity of the OE muscle and level of functioning

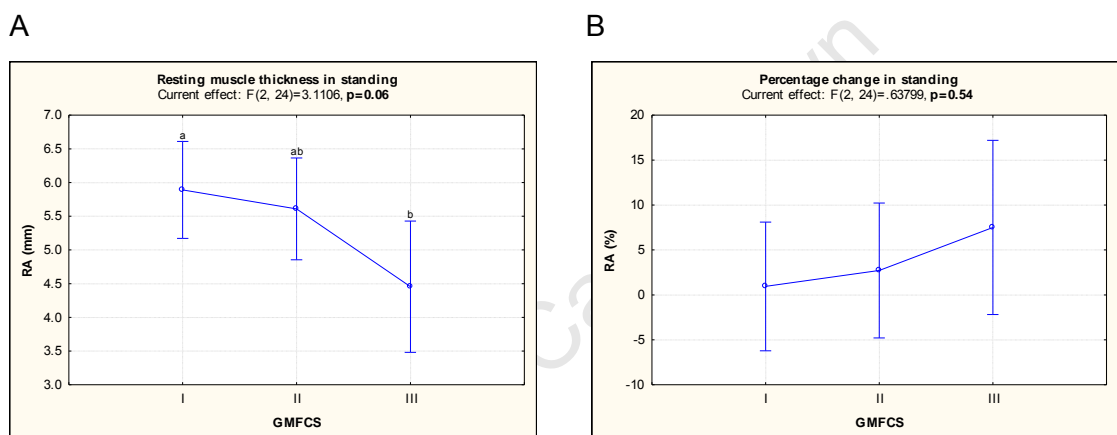


Figure 25 A: Comparison of resting RA muscle thickness measurements in standing and level of functioning; **25 B:** Comparison of % change during contra-lateral leg lift activity of the RA muscle and level of functioning

5.4.4 Predictor value of muscle thickness measurements

5.4.4.1 Variables predictive of distance walked

BMI, a dummy variable for gender, the degree of a-p pelvic tilt and the number of sit-ups recorded in one minute together with all the thickness measurements recorded in the supine position were entered into an all subset regression model to determine the predictors for distance walked in one minute. The percentage change that was calculated for the OE muscle during the head-up activity in supine however was not included (Table 34) as the measurement of thickness during activity was consistently thinner than that recorded during rest. It is unclear whether this is due to the muscle being stretched or compressed by the contracting OI and RA (and possibly TrA)

muscles and without EMG verification it can only be assumed at this point that there is also no activity in this muscle during the head-up action in this supine position and it was deemed appropriate to exclude this variable from this regression model.

Inspection of R^2 using thickness measurements recorded in the supine position resulted in the selection of the final model (Table 34) which indicated only two variables to be predictive of distance walked in one minute. The model generated explains 42% of the variance.

Table 34 Regression summary for variables (recorded in supine) predictive of distance walked (m) $R=0.684$ $R^2=0.468$ Adjusted $R^2= 0.424$

Variables entered into the model	b	SE- of b	t(24)	p-value
<i>Intercept</i>	79.87	5.49	14.56	0.000
<i>no of sit-ups in 1min</i>	1.06	0.33	3.270	0.003
<i>% change OI (%)</i>	0.47	0.19	2.487	0.020
Age (yrs)	excluded			
M/F				
BMI (kg/m ²)				
Standing pelvic tilt (°)				
Resting TrA (mm)				
Resting OE (mm)				
Resting OI (mm)				
Resting RA (mm)				
% change TrA (%)				
% change RA (%)				

Similarly BMI, gender, the degree of pelvic tilt and the number of sit-ups recorded in one minute together with all the thickness measurements recorded in the standing position were entered into an all subset regression model to determine the predictors for distance walked in one minute. As the OE muscle was recruited during this activity – as was seen in the positive change in thickness recorded during the activity – it was included in this analysis.

Inspection of R^2 using thickness measurements recorded in the standing position resulted in selection of a model which indicated three variables to be significantly

predictive of distance walked in one minute (Table 35). This model explains 39% of the variance.

Table 35 Regression summary variables (recorded in standing) predictive of distance walked in one minute (m) $R = 0.710$ $R^2 = 0.505$ Adjusted $R^2 = 0.387$

Variables entered into the model	b	SE - of b	t(21)	p-value
Intercept	41.72	26.72	1.56	0.133
Standing pelvic tilt(°)	0.94	0.91	1.02	0.318
<i>no of sit-ups in 1min</i>	2.12	0.61	3.46	0.002
% change OE (%)	0.37	0.19	1.98	0.060
% change OI (%)	0.48	0.21	2.31	0.031
% change RA (%)	-0.55	0.38	-1.44	0.164
Age (yrs)	excluded			
M/F				
BMI (kg/m ²)				
Resting TrA (mm)				
Resting OE (mm)				
Resting OI (mm)				
Resting RA (mm)				
% change TrA (%)				

5.4.4.2 Variables predictive of degree of pelvic tilt

The same variables (BMI, gender, and the number of sit-ups recorded in one minute) together distance walked in one minute and all the thickness measurements recorded in the supine position were entered into an all subset regression model to determine the predictors for degree of pelvic tilt. In this case the final model selected (Table 36), which explains 40% of the variance, shows three variables to be predictive of degree of pelvic tilt – BMI, number of sit-ups in one minute and resting thickness recorded in the standing position.

Table 36 Regression summary of variables (recorded in supine) predictive of degree of pelvic tilt (°) R= 0.715 R²=0.511 Adjusted R²=0.395

Variables entered into the model	b	SE - of b	t(21)	p-value
<i>Intercept</i>	30.71	7.66	4.01	0.001
M/F	2.55	1.96	1.30	0.207
BMI (kg/m²)	-0.78	0.37	-2.14	0.044
distance (m)	-0.05	0.05	-1.09	0.287
no of sit-ups in 1min	-0.21	0.10	-2.05	0.050
Resting OE (mm)	2.12	0.82	2.58	0.017
Age (yrs)	excluded			
Resting TrA (mm)				
Resting OI (mm)				
Resting RA (mm)				
% change TrA (%)				
% change OI (%)				
% change RA (%)				

Similarly BMI, gender, the distance walked and the number of sit-ups recorded in one minute, together with all the thickness measurements recorded in the standing position were entered into an all subset regression model to determine the predictors for degree of pelvic tilt. The final model selected was a better one which suggests that these five variables (Table 37) account for 62% of the variance.

Table 37 Regression summary of variables (recorded in standing) predictive of degree of pelvic tilt (°) R= 0.833 R²=0.695 Adjusted R²=0.622

Variables entered into the model	b	SE of b	t(21)	p-value
<i>Intercept</i>	31.13	5.31	5.87	0.000
M/F	2.71	1.60	1.70	0.105
BMI (kg/m²)	-0.88	0.29	-3.06	0.006
no of sit-ups in 1min	-0.40	0.07	-5.53	0.000
Resting OE (mm)	2.61	0.84	3.11	0.005
% change OI (%)	-0.13	0.03	-4.00	0.001
Age (yrs)	excluded			
distance (m)				
Resting TrA (mm)				
Resting OI (mm)				
Resting RA (mm)				
% change TrA (%)				
% change OE (%)				
% change RA (%)				

5.4.5 Summary of results

In a group of six to 13 year old children with STCP significant correlations were found between impairment in terms of degree of a-p pelvic tilt and functioning in terms of number of sit-ups executed and distance walked in one minute. The greater the degree of tilt, the less sit-ups the children could perform. In addition, children presenting with a greater a-p pelvic tilt covered less distance in one minute during walking and those who had stronger abdominal musculature were able to walk longer distances in one minute.

No clear relationships between abdominal muscle thickness measurements and measurements of impairment and functioning were found. There is some evidence that selected measurements for the OE and OI muscles are related to a-p pelvic tilt, abdominal muscle strength and gait. For measurements recorded in the supine position (either at rest or during the head-up activity) no relationship with level of functioning

was found. There was however a tendency for higher functioning children to have a greater amount of change in thickness measurements from rest to head-up. No relationship was found between resting thickness measurements recorded in standing and level of functioning. Significant correlation was found however between percentage change in the OE muscle during the contra-lateral leg lift activity and level of functioning.

Further inspection of this relationship using regression analysis produced similar results also suggesting that the percentage change that occurred in the OI muscle during the head-up activity in supine as well as during the contra-lateral leg lift activity in standing is associated with distance walked in one minute. Measurements recorded for the OE muscle in both supine and in standing were associated with the degree of a-p pelvic tilt as well the percentage change recorded in the OI muscle recorded in standing. BMI was significantly associated with both posture in standing and distance walked in that children with a larger body stature presented with a greater anterior pelvic tilt and were unable to cover the same distance in one minute than children with a smaller body stature.

5.5 Discussion

The results of the current study suggest that there is a relationship between abdominal muscle functioning and posture and gait in children with STCP. Children with weaker abdominal muscles presented with a greater a-p pelvic tilt and similarly did not cover the same distance while walking in one minute as children who were able to perform more sit-ups. Following a brief discussion of the sample demographics, the relationships between impairment and functioning are discussed. As this study also explored the utility of abdominal muscle thickness measurements recorded using ultrasound imaging, relationships between selected thickness measurements and posture and gait were also investigated and are discussed below.

5.5.1 Sample representation

As 70 – 90% of children with CP present with the spastic type motor dysfunction^{27;147}, it was deemed appropriate to limit the sample and include only children with this type.

The sample was further limited in that only children with diplegic and hemiplegic distribution were included in the study as these two groups represent >60% of children with spastic type CP²⁷. While the findings of the current study could be generalisable to all children with spastic type CP² stringent inclusion criteria does affect external validity. Although there is uncertainty regarding the presence of spasticity in the abdominal muscles (Chapter 2) the findings of the current study may be generalisable to all children presenting with spastic type CP, but not to children with variable, dystonic and / or low tone.

Only participants classified as Level I, II or III according to the GMFCS were included in the current study as the posture and functional activities investigated were limited to standing posture and gait function. It is hypothesised that similar correlation(s) may exist between abdominal muscle functioning and non-weight bearing and / or upper limb activity (refer to 2.2).

5.5.2 The relationship between abdominal muscle functioning and posture and gait

Despite the limitations of the outcome measures selected in the current study (refer to 5.6.2) significant correlations were found between abdominal muscle strength, gait function, posture and levels of functioning. Children with weaker abdominal musculature presented with a greater degree of anterior pelvic tilt. Similarly children with weaker abdominal musculature could not cover the same distance as those with better abdominal functioning.

The influence of musculo-skeletal alignment on muscle functioning is well described in the literature. A muscle is able to produce optimal force when the fibres are slightly stretched, but remain within the mid-range of movement where optimal cross-bridge formation between the actin and myosin filaments can occur^{68;265}. An exaggerated anterior pelvic tilt and an increased lumbar lordosis potentially over lengthen all four abdominal muscles. This is supported by the current study results in that the measurements recorded for the TrA, OE and RA muscles in the standing position where no adjustments to posture were made, were significantly thinner than those recorded in the supine position in which the pelvic tilt was 'neutralised' as far as it was possible (Chapter 4). Children with CP differed significantly from children with TD in

terms of the ability to recruit the abdominal muscles in a supine position and although not investigated in the current study, similar or even greater differences could be expected to be seen in the standing position. Children classified as Level III in terms of functional ability presented with significantly greater a-p pelvic angles and similar significantly thinner RA muscles and had poorer gait function when compared to children classified as Level I supporting the assumption that posture and abdominal muscle functioning are related to gait. Gage (2004) demonstrated that the poorer gait function in CP is also associated with a shortened stride length when compared to children of TD affecting the ability to walk at faster speeds⁸⁷. While neither this parameter nor the strength of the hip flexors were measured in this study, results suggest that Bly's hypothesis regarding abdominal muscle weakness or inactivity being one of the contributing factors to the exaggerated anterior pelvic tilt and resultant impaired hip flexion⁸⁴ may be correct.

Although no comparisons were made with children with TD, children with CP who presented with a poorer gait function were unable to execute as many sit-ups as their more functional peers. At this point, without accurate description of the pathophysiological changes which are well described in the literature as causative factors for the weakness the upper and lower limb muscles¹⁵⁶ it can only be assumed that similar changes may be present in the abdominal musculature of persons with CP; and that in children with lower motor function, the influence or presence of these factors is greater. In a typically developing population a decrease in cross sectional area and a shorter fascicle length are associated with disuse and increasing age¹⁵⁷ and Moreau et al. (2009) hypothesised following their investigation into the size of the rectus femoris and lateralis muscles that the lower activity and mobility levels in children and adolescents with CP when compared to children of TD are further possible contributing factors to muscle weakness in the CP population.

Core stability requires synchronised co-contraction between various muscle groups. Although the local stabilisers of the trunk function independent of movement^{24;70;350}, in standing and during activities in stance for example the ventral abdominal musculature and hip extensors (posterior fibres of gluteus maximus) co-contract to stabilise the pelvis⁷⁰. Weakness of the hip extensors may therefore affect the ability of the ventral muscles to contract. Weakness of both the gluteus maximus and hamstring muscles are well documented in persons with CP^{61;87;184;229;247;266;369} but without a more

comprehensive profile of lower limb muscle strength no clear conclusion can as yet be drawn regarding the contribution of abdominal muscle strength to gait function.

Regarding the strength of the abdominal muscles, it should be noted that large variation occurred between individuals and although the results of the current study suggest that children classified at a lower level presented with weaker abdominal muscles, not all children presented this way. Not all individuals classified as Level III had weak abdominal muscles and similarly some individuals classified in Levels I & II were unable to execute any sit-ups at all. Almost all of the participants unable to execute sit-ups independently however presented with poorer gait function in that they covered less distance than the mean for the group (<90m). Despite better abdominal muscle strength (for those individuals in Level III), the impact on gait appeared negligible. Changes in the viscoelastic properties of muscle due to spasticity may cause pseudo weakness in that the muscle may not be strong enough to overcome the resistance and negatively impact motor performance¹⁵⁶. But without evidence that spasticity was present in the abdominal muscles of children participating in the current study, this hypothesis remains unchallenged.

Although US imaging has been shown to be a reliable instrument for measuring architectural parameters such as cross sectional area, fascicle angle and -length^{63;158}, this exceeded the aims of the current study and were not investigated. The findings utilising ultrasound imaging from this and previous studies (Chapters 3 & 4) suggest that children do contract - albeit it varied - and exhibit activity in all four the ventral muscles. However without EMG verification it is not certain that the change in thickness recorded during selected head and limb movement correlates with the level of activity (\approx strength?) in each of the muscles. Because of the heterogeneity of CP and a whole host of secondary impairments, a cause and effect relationship regarding weakness in the abdominal muscles remains uncertain.

Regression analysis in which demographic characteristics were also entered into the analysis suggests that body mass index (BMI) also significantly predicts gait function. Children with a greater BMI walked more slowly. This could have been mediated through the degree of pelvic tilt as those with a higher BMI also presented with a greater degree of pelvic tilt. As none of the children in the current study were however overweight - a BMI of $>25\text{kg/m}^2$ disqualified participants from taking part - the effect of

increased adipose tissue on the ability of the abdominal muscles to contract and execute sit-ups remains unknown.

The primary function of the abdominal muscles during self-selected walking speed seems to be to provide stability and maintain upright posture and activity in these muscles is in response to lower limb activity¹²³. However these muscles are unable to optimally perform the stabilising function without concurrent and synchronised co-contraction in the synergist muscles. In persons with CP exaggerated trunk activity is seen which is a compensatory mechanism for weakness in the lower extremities⁸⁷ and is necessary for forward propulsion. The question remains whether increasing the strength of the abdominal muscles and activating inactive muscles can improve posture and gait function in this population.

5.5.3 The relationship between abdominal muscle thickness measurements and posture and gait

Moreau et al. (2009) observed that the differences in muscle architecture between children with CP and TD reflect the inherent functionality and morphology that is specific to each muscle. Although cross sectional area, fascicle length and -angle parameters were not investigated in the current study, nor biopsies conducted to determine the fibre type composition, the muscle thickness measurements recorded using ultrasound imaging did allow for limited investigation into each of the four abdominal muscles. The resting thickness and the ability of these muscles to contract and their association with posture and gait are discussed below.

The results from a previous study (Chapter 3) as well as this study, in the absence of evidence that tone in the abdominal musculature is abnormal or increased, confirm that children with STCP classified as Level I, II or III can recruit their abdominal muscles during activity in the supine as well as in the standing position. Differences in patterns of recruitment during different activities suggest an ability to selectively recruit each of the four abdominal muscles and that the pattern is dependent on the demand placed on these muscles. For example the TrA, OI and OE were poorly recruited (no significant difference was found between thickness measurements recorded during rest and during contracted state) in the supine position, while in the standing position there was a significant increase in percentage change recorded in TrA, and OI muscles,

together with a significant decrease in the recruitment of the RA during contracted state. Although B-mode US imaging was utilised in these earlier studies, several images are recorded for 5 seconds prior to the final image captured. It was noted that when the leg lift was initiated the thickness of the OE as well as TrA and OI muscles increased significantly, but by the end of the activity where the child was asked to hold the leg in the flexed position, activity in the trunk 'stabilised' and while a decrease in thickness in some of the muscles was seen, an increase in others was noted. M-mode imaging^{83;319} throughout the activity may be more useful for description of patterns of activity.

5.5.3.1 Transverse abdominis muscle (TrA)

Although no correlation was found between resting thickness of this muscle and level of functioning, in the standing position a significant inverse correlation was found between resting thickness of the TrA (and to a lesser extent the OI muscle) and the degree of pelvic tilt as well as the ability to execute sit-ups. These findings support the hypothesis that underlying abdominal muscle strength/functioning contributes to the better posture in standing. Despite children with CP presenting with thicker TrA muscle (Chapter 4), the diameter of this muscle remained consistently thin across the three levels of motor function suggesting that this muscle is seldom used. The small percentage changes recorded during activity in both the supine and standing positions also suggest that in children with CP this muscle is relatively inactive and is poorly recruited during activity. Despite participants being positioned in a fully supported supine position, the TrA muscle is responsible for stabilising the lumbar spine and pelvis which allows the OI and RA to provide stability to the thoracic cage⁷⁰ which in turn would allow for a stable base of support for the neck flexors to tuck in the chin and lift the head off the plinth. It may be argued that the fully supported position reduces this need however and explains the negligible percentage change recorded. Although the difference was significantly bigger than that recorded in supine, the percentage change recorded in the standing position remained small while lifting the contra-lateral leg. As activity in the muscles is determined by demand, concurrent motion analysis would confirm the relevance of this association.

For some individuals a negative percentage change during both the head lift and leg lift activity was recorded suggesting that the muscle was stretched during activity.

Whether this was due to changes in thoracic and pelvic positioning/alignment due to an overactive RA muscle or due to weakness of the TrA muscle or both and whether there

is activity in the TrA muscle while being stretched is still unknown and can only be confirmed using EMG.

5.5.3.2 *Obliquus internus muscle (OI)*

Being the thickest muscle in children with CP (and also the only muscle which did not differ significantly in thickness between that recorded in the supine and standing positions) compared to the RA muscle in children with TD (Chapter 4) it was postulated that this muscle is more often recruited / active in children with CP. Whether the relatively thicker OI muscle seen in standing (compared to the other three abdominal muscles) may be due to increased activity demanded in stance for stabilising the spine or whether this is due to an increase in (dynamic?) tone¹¹⁹ is unknown. Regression analysis investigating parameters predictive of the position of the pelvis and self-selected fast walking suggest that the level of OI muscle contraction is predictive of posture and gait function.

Despite being the thickest muscle suggesting this muscle is the stronger and/or more utilised muscle compared to the TrA and RA muscles - the percentage change which occurred during activity in both the supine and standing positions was small. While it could be said that for effective energy efficient stabilisation of the trunk the level of activity should be low, without EMG verification and concurrent motion analysis it cannot be concluded that the small change recorded is suffice or purposeful. No significant difference in resting thickness or for the percentage change recorded during activity across the three levels of functioning was found either suggesting that regardless of functional ability this muscle may be consistently active at a low level. The extent of the contribution of this muscle to posture and function however needs further investigation.

5.5.3.3 *Obliquus externus muscle (OE)*

These muscles were the thinnest of the four abdominal muscles and as their contribution to trunk stability is very small, negligible change in recruitment during the activities selected in the current study was expected. The results of the study suggest that this muscle was not recruited in supine ($p=1$ across the three level of functioning). The negative mean value for percentage change during activity suggests these muscles were stretched, but whether this is due to biomechanical changes as

discussed previously or whether they are compressed by overactive RA is as yet unknown.

Unilateral activity places an asymmetrical load on the trunk and demands activity of the rotator mover muscles to contribute to stability of the trunk^{71;83}. It was assumed that the contra-lateral leg lift activity in one leg stance would result in activity in the OE muscle to counteract the rotational force imposed on the trunk. However while children in Levels I and II in the current sample showed no or negligible change in thickness, children in level III recruited this muscle significantly more during this activity. This resting thickness of this muscle in the standing position was shown to be predictive of both position of the pelvis and distance walked. It is postulated that the increased demand on this rotator mover muscle occurred as a result of poorer stance stability or alternatively collective lower limb muscle weakness. 3D motion analysis could be used to determine whether this change in thickness correlates with degree of hip flexion.

5.5.3.4 Rectus abdominis muscle (RA)

Although not the thickest muscle in children with STCP, this was the only muscle which presented with a positive percentage change in all participants during the head lift activity in the supine position. This was however not unexpected. Children in the current study were asked to tuck in their chin and lift their heads off the plinth and asked to hold the position. The image was almost immediately recorded as children were unable to hold the position for longer than a few seconds. It is postulated that the RA was recruited to function primarily as stabiliser due to the poor recruitment of the TrA and OI muscles, and as it is presumed that this muscle contains predominantly Type I fast twitch fibres, early fatigue rendered the muscle incapable of maintaining spinal and thoracic stability, without concurrent TrA and OI contraction. Also without concomitant gluteus maximus functioning, the pelvis would have been pulled into a posterior tilt further rendering the RA less efficient for maintaining spinal stability.

In the standing position it was hypothesised that the RA would also be predominantly recruited in that it was assumed that the TrA and OI muscles are weak in children with STCP. The contracting RA would facilitate a shift of the pelvis into a more posterior tilt in order to facilitate better hip flexion. However the percentage change which occurred in standing in the RA muscle was significantly less than the recruitment recorded in the supine position. Although observation of the activity suggests that the pelvis remained in an anterior tilt (in some children this tilt became even more exaggerated), more

objective concurrent motion analysis would confirm this association of pelvic positioning and abdominal muscle activity. A higher percentage change was however recorded in the TrA and OI muscles suggesting that the higher the demand of the activity, recruitment of the more appropriate musculature occurred.

Some participants exhibited a negative percentage change suggesting that in these participants this muscle was stretched during the leg lift activity. It is presumed that the activity was associated with hyperextension of the trunk - stretching the RA, to passively tilt the pelvis more posterior thereby facilitating hip flexion. Correlation of muscle activity with 3-D motion analysis is suggested in order to understand these relationships better.

As were the findings in the ultrasound reliability study, it was noted that large variation was found between individuals for all four abdominal muscles. The variation in thickness measurements recorded in the supine position, although not significant, was greater for children classified as Level III than for children in Levels I and II, while the mean calculated value for the percentage change was lower for children classified in level III. These results suggest that while children classified with a lower level of functioning (and who presented with a greater degree of pelvic tilt) may have more difficulty in recruiting abdominal muscles for stabilising the trunk during head and lower limb activity, other factors may also influence the ability of these muscles to contract. Furthermore some individuals in Level III were able to perform more sit-ups than some in Level II, although this apparent better strength did not result in improved distance walked in one minute. This suggests that not all children with a lower level of functioning present with weak(er) abdominal musculature and similarly not all children with 'good' gait function have 'good' abdominal muscle strength.

5.6 Limitations

This study has several limitations which are discussed below.

5.6.1 Sample selection

As this study was a novel investigation into abdominal muscle activity, a sample of convenience was selected. Initial sample size calculation was conducted on the basis of the primary outcome measure (distance walked in one minute) and although the sample size was deemed adequate the large variation found in the other selected variable parameters did not allow for sufficient power to analyse sub-groups. The all subset regression analysis used in the current study highlights the need for a more comprehensive analysis of an individual's total strength profile, and demographic and anthropometric characteristics prior to research subject selection.

All participants were selected from one institution only. Although not investigated in the current study, sport and therapy programs differ between schools for children with special education needs and as such may have influenced the baseline measurements. A study by Hides et al. (2006) showed that the thicknesses of all four abdominal muscles in elite cricketers were significantly thicker than in untrained athletes. Table 23 (refer to 4.5.1) lists the mean thickness measurements from various studies in subjects with and without low back pain which further support the assumption that level of activity is influential in muscle thickness measures.

5.6.2 Outcome measurements used

As this was an intensive descriptive study in which participants were subjected to numerous measurement tools, the outcome measures (OMs) used in the current study for investigating abdominal muscle strength and activity, posture and gait were selected on the basis of their clinical feasibility. Although a pilot study was conducted to demonstrate test-retest and tester reliability, the measurements are limited in their representation of posture and gait and are discussed further below.

Abdominal muscle strength In the current study abdominal muscle strength was measured by looking at the number of sit-ups a child could perform in one minute^{303;370} as all aspects of abdominal muscle functioning – power, strength and endurance, are incorporated in this activity. While it was presumed that all participants had 'equal opportunity' to execute the activity (refer to 5.3.3.1), weakness of the lower limbs and differences in body stature were not accounted for.

Abdominal muscle activity Measurement of abdominal muscle thickness was deemed a valid measurement (Chapter 3) in this population and as such percentage change in thicknesses which occurred during selected activity of the head and or lower limbs in all four abdominal muscles were calculated for investigation into patterns of recruitment. While change was detected during activity in all four abdominal muscles large variation (including a decrease or a thinning of the muscle during activity) was found within individual cases. Without EMG verification, it can only be assumed at this stage that negligible or even no activity occurred in these muscles and therefore the contribution to the performance of the head and or leg lift activities negligible (or absent) in these participants. Similarly although resting thickness measurements were correlated with the number of sit-ups executed (i.e. strength), the relationship between thickness (and/or change in thickness) is still speculative.

Gait Walking ability or function was investigated using the one minute walk test which records the distance a child is able to walk in one minute. Although not frequently cited in the literature, McDowell et al. (2009) demonstrated test-retest reliability for determining gait function in children with spastic type diplegia²⁷³ and advocated the use of this measurement for its clinical feasibility in the absence of a gold standard measurement such as the GMFM or a 3-D motion analysis system. Gait is a complex functional activity which allows for forward propulsion over varied terrain, at varied speeds including the ability to change direction. Various components contribute to efficient gait and limiting this investigation to fast walking on flat terrain only while exploring relationships with abdominal muscle activity might have underrated the contribution of abdominal muscle activity to gait function. Correlation analysis of 3-D kinematic parameters of the trunk and abdominal muscle strength may more accurately determine the contribution of these muscles to the gait patterns seen in CP.

A-P pelvic tilt Two dimensional photographic postural analyses was utilised in the current study but only one variable, namely the degree of a-p pelvic tilt was used to investigate the relationship between abdominal muscle strength and posture and its influence on lower limb function. While the current study was interested in the relationship between abdominal muscle strength and the position of the pelvis in particular, analysis into causation cannot be based on this single parameter. In standing without acknowledgement of the contribution of the degree of ankle and knee kinematic measurements the influence of the abdominal muscles may have been over or even under-estimated. The inconsistent finding relating to strength and function in

individuals suggests inclusion of multiple kinematic parameters may be more appropriate when investigating the role of the abdominal muscles in lower limb function.

5.6.3 Variables measured

The focus of all the studies contributing to the main aim of the study was description of the abdominal muscles in terms of thickness (\approx strength) and level and or pattern(s) of activity. As previously described, the primary functions of the core /trunk musculature is to provide stability to the trunk during upright posture and activity. The abdominal muscles form an essential part this 'cylinder' supporting the vertebral column and although activity in each of the four abdominal muscles is different (refer to 2.2, 3.4 and 4.4) effective functioning is dependent on the collective functioning of all the contributing muscles. This became apparent in that there was lack of consistency regarding resting muscle thickness measures between individuals as well as in ability to recruit each muscle during activity. Without more comprehensive assessment of all parameters involved including the trunk, pelvic and shoulder girdle stabilisers, functioning of the abdominal muscles and their role in posture and function remains speculative.

Ultrasound imaging and measurement of abdominal muscle thickness was recorded in the supine position and compared with measurements recorded in standing. Although the current study only investigated isometric truncal activity as it was assumed that similar recruitment of abdominal muscles as was recorded in standing would occur during gait. No correlation however between thickness measures (during rest or contraction) in either position was however found despite there being significant associating between abdominal muscle functioning and gait. A study by Anders et al. (2007) concluded that albeit that there were differences between individuals for each muscle, the changes in EMG activity in all four abdominal muscles collectively were associated with increasing gait speed¹²³. Collective functioning was not investigated in the current study.

5.7 Recommendations

5.7.1 Recommendations for consideration when planning intervention

The following recommendations are suggested for consideration when planning (re)habilitation aimed at improving particularly gait function in children with STCP:

- Include abdominal muscle strengthening exercises where these are identified as being unable to generate appropriate force.
- Be selective in the type of exercise keeping in mind that the abdominal muscles function primarily as stabilisers of the trunk during gait – also remembering that children with a weak lower limb strength profile utilise the abdominal muscles for compensatory strategies.

5.7.2 Recommendations for future research

Further research is also recommended to better understand relationships and the contribution of the abdominal muscles to function and includes:

- Concurrent 3-D motion analysis of the movement or activity utilised to inspect changes in the abdominal muscles.
- Increase sample size to allow for subgroup analysis³⁷¹, inclusion of all types of CP and various learning institutions.
- The results of the current study also suggest that more comprehensive analysis of strength profiles (including that of the abdominal muscles) and anthropometric measures and demographic characteristics be conducted.
- Verify activity in the abdominal muscles using EMG and correlate with US imaging thickness measurements.
- Explore architectural parameters - cross sectional area, fascicle angle and – length - of the abdominal muscles and their relationship with muscle strength for comparison with other skeletal musculature. Ultrasound imaging and magnetic resonance imaging (MRI) is suggested.
- Validity and reliability of M-mode US imaging as described by Bunce et al. (2004) should be investigated which will allow for description and further exploration of abdominal muscle activity during functional activities such as during gait in children.

- Correlation of the clinical outcome measures used in the current study with 'gold standard' laboratory measures in order to verify validity is needed.

5.8 Conclusion

This study provides evidence that in children with STCP aged six to 13 years there is a relationship between the degree of pelvic tilt, functioning of the abdominal muscles in terms of the ability to execute sit-ups and gait. There seems to be an indication that better functioning children can activate their abdominal muscles better. Children with STCP can activate abdominal muscles selectively depending on position and load but due to the abnormal range in which these muscles must function, the level of performance is affected. These results suggest that strengthening the abdominal muscles may result in improved posture and therefore gait function.

Regarding the utility of US imaging, the current findings suggest that abdominal muscle thickness is not a good indicator of function, mostly because there seems to be such a wide variation - not all children with lower functional classification presented with thinner, weaker abdominal musculature than children with a higher level classification. Similarly children despite apparent thicker abdominal musculature did not recruit selected abdominal muscles 'better' than children with thinner muscles. When using US imaging as an outcome measure the variable of interest should be the percentage change recorded between resting and contracted states, and pattern of recruitment in all four abdominal muscles rather than an increase in diameter or thickness. More description regarding muscle morphology of the abdominal muscles is needed.

Effect of a trunk-targeted intervention on pelvic positioning and lower limb function in children with spastic type cerebral palsy

6.3 Background

Strengthening the trunk or core musculature has become and remains one of the primary focus areas for improving motor performance, despite ongoing debate in the literature. This is especially true for performance on the sports field^{114;372}. Retraining and strengthening the core stabilizers has resulted in improved rehabilitation outcome and there has been a decrease in recurrent injury reported following core-targeted intervention^{26;373}. It is hypothesized that providing a more stable base of support allows for more controlled and directed movement. In a population such as those with cerebral palsy, in which many researchers hypothesize that the underlying postural problems and range of ambulation and upper limb activity limitations are due to lack of postural control^{49;119;211;317}, it could be argued that strengthening the trunk or core stabilizers could significantly impact motor function.

The current thesis aimed to describe the role of the abdominal musculature in lower limb function in children with spastic type cerebral palsy (STCP) with regard to strength and recruitment activity in order to help researchers further their understanding of the strategies used by these children for forward propulsion, locomotion and function. Following analysis of the data following the ultrasound imaging reliability studies in children it was noted that children with STCP do not recruit their abdominal muscles in a similar manner to that seen in children with typical development (TD) (Chapters 3 and 4). For example, very little to no recruitment of transversus abdominis (TrA) and obliquus internus (OI) activity was seen in subjects lying in supine during activity of the head or lower limbs. Although little activation of the TrA is also seen in age-matched children with typical development (TD), the pattern of abdominal muscle recruitment differs to those seen in children with CP. Children with CP used rectus abdominis (RA) for all movement or maintenance of posture with very poor recruitment of the stabilisers whereas children with TD do recruit TrA and OI more and rely less on RA activity during the same activity (Chapter 4).

A major finding of previous chapter was that the degree of pelvic tilt and abdominal functioning are related to lower limb function. Therefore improving the pelvic tilt and strengthening the abdominal muscles might improve gait. Also the increased muscle thickness at rest seems to prevent good activation. It was hypothesised that this thicker appearance may be due to spasticity and if this is somehow decreased, functional range of contraction could be increased. The current study hypothesized that an intervention specifically targeting the abdominal muscles in children with STCP would improve posture and impact lower limb activity and function.

6.4 Literature Review

Acquisition of a more stable base of support for improved postural control and motor performance involves a complex integration of many systems – vestibular, visual and central and peripheral nervous system functioning and assimilation³⁷⁴. The influence of the environment and individual psyche also impact on the effectiveness of any intervention targeted at improving balance and motor performance. Although the role of the vestibular and visual systems cannot be ignored, this additional literature review is limited to discussion concerning interventions aimed at targeting and strengthening the core stabilizers. Chapter 2 concluded that the literature pertaining to description of abdominal muscle functioning in cerebral palsy is sparse. There is also paucity in the literature regarding trunk-targeting interventions within this population. This supplementary review includes a discussion on the efficacy of trunk targeting interventions in cerebral palsy, with particular emphasis on the use of abdominal or trunk strengthening to improve function. There is also description of interventions targeting the trunk musculature used in other populations. The use of specific vibration technology for facilitating muscle contraction and strengthening is also discussed.

6.2.1 Trunk targeting interventions in cerebral palsy

Traditional physiotherapeutic approaches for treating and managing persons with cerebral palsy are mostly based on facilitation of normal movement and inhibiting abnormal movement patterns (Chapter 2). An improved understanding of the underlying pathology and development of motor patterns in children with CP^{50;163;211;212} however suggest that specifically targeting the primary impairments resulting from the

brain lesion i.e. reducing spasticity²¹³⁻²¹⁵, strengthening weak musculature^{40;89} and correcting biomechanical malalignment²¹⁶ can improve not only cosmetic appearance, but also significantly impact function. Most of these interventions however target the limbs and seldom make specific reference to targeting the core or trunk musculature. There is some evidence that lower limb strength profiles and range of movement are decidedly correlated with balance²⁹⁵. Despite the growing literature reporting on investigations into progressive resisted strength training and its impact on lower limb function for persons with CP^{8;17;40;89;375;376} a recent systematic review published in 2009, concluded that there is no conclusive evidence for safety or efficacy¹⁶. This conclusion predominantly stems from the lack of methodological rigour as well as lack of appropriate control in many of the studies published. Large variation and no clear patterns among individual participants also contributed to the negative outcome following resistance training in this population.

The efficacy of specific trunk-targeted strengthening and the contribution of the trunk to lower limb function are seldom discussed. Some studies were found in which interventions were directed at strengthening or targeting the trunk musculature for improving postural control and or balance. One study by Park et al. (2001) investigated the effect of the application of electrical stimulation to the abdominal and back musculature in six to 18 month old infants²²⁵. The authors reported a significant improvement in sitting posture and trunk control using radiographic imaging when compared to a control group. Another article, a summary of six single case studies, reported on the effect of a targeted intervention in children aged two to seven who could not sit independently⁷⁴. The intervention involved a movable seating device and all six subjects gained independent seating within ± 16 months. This study however had no control group and impact of intervention may have been overestimated.

Interventions such as therapeutic horseback riding have also reported improved posture and balance in children with CP. Bertoti et al. (1988) using a self-designed postural balance scale reported significant improvement in posture as well as clinical improvements in lower limb muscle tone and balance in children aged two to nine years old²³⁴. A more recent single blinded, case controlled study in children with CP reported significant improvement in function (i.e. Gross Motor Function Measure (GMFM) total scores) immediately following hippotherapy²⁵⁶. These improvements however were not maintained and GMFM total scores returned to baseline six weeks

after the riding therapy had stopped. There was however a carry-over effect reported for Dimension E (walking, running and jumping) at six weeks post-intervention.

The above studies are all relatively low level ranked, either without control or subjects served as their own control, sample sizes were small and except for the GMFM, reliability of outcome measurements used is questionable. Further more rigorous studies aimed at improving standing balance⁴⁶⁻⁴⁸ have also reported significant improvements, but did not specifically report on the various factors or components contributing to the total outcome i.e. balance.

A randomized control trial investigating the effect of an eight-week progressive resisted exercise program in circuit format in adolescents with STCP included abdominal and back extensor exercises⁴⁵. The authors however reported that inclusion of the trunk in their exercise program did not result in 'better' gait performance compared to outcome reported in studies investigating only lower limb targeted strengthening programs, despite apparent increase in abdominal muscle strength as measured by the change in the number of independent sit-ups executed. The type of exercise selected for strengthening in that study however included mainly isotonic muscle activity. No specific exercises aimed at recruitment or strengthening of the TrA and/or OI as stabilizers were included in this study. Stackhouse et al. (2005) suggested that because children with CP demonstrate large deficits in voluntary muscle activation using voluntary contractions for strength training may not produce forces sufficient to cause muscle hypertrophy. The authors recommended that techniques such as enhanced feedback and neuromuscular electrical stimulation may be more helpful for strengthening muscles that cannot be sufficiently recruited with voluntary effort alone⁶⁰.

The more 'traditional' techniques used by physiotherapists such as ice brushing, tapping - use of stretch reflex²⁵⁷, compression and distraction²⁵⁸, shaking and manual vibration²⁵⁹ could possibly be applied to the abdominal musculature in order to recruit and facilitate abdominal muscle activity. The core abdominal muscles however are deep muscles and these techniques not always effective, especially in children who may be sensitive to touch resulting in activation of the more superficial obliquus externus (OE) and RA, and not necessarily the stabilizer muscles. The evidence for the efficacy of these techniques is however also not well described.

6.2.2 Typical trunk targeting interventions

Isometric progressive resisted exercise (PRE) targeting the abdominal and back musculature is the most common intervention for strengthening and improving trunk core stability function^{96;370;373;377;378}. Exercises are typically executed, beginning in a fully supported supine and/or prone position, gradually progressing to a less stable surface and or decreasing the base of support. Body weight and movable surfaces such as balls, bozu balls (half balls) and balance boards are also used to progressively increase load on these muscles^{373;378}. Although the evidence for improved core stability on motor performance in peak performing athletes is inconclusive^{114;372}, there is varying response reported for individuals following participation in core targeted interventions^{96;378}. There is however increasing evidence for the efficacy of core targeted strengthening exercise in rehabilitation and for prevention of recurrent injury^{26;373} and for treatment and management of chronic low back pain^{116;379}.

6.2.2.1 Vibration technology

The use of vibration as an exercise was first introduced by scientists investigating interventions effective for reducing muscle atrophy experienced by Russian cosmonauts while in outer space. Although studies investigating effects of vibration on motor performance have reported varying benefits associated with vibration training especially in those studies reporting on the immediate effect³⁸⁰⁻³⁸², exercise using vibration technology has gained 'popularity' in the adult fitness arena and more recently in the field of rehabilitation. Training using vibration platforms has shown to be effective in increasing strength^{383;384} especially in the postural muscles, resulting in improved balance and coordination^{382;385;386}.

Vibration effectively provides perturbation of the gravitational field during the course of the intervention^{387;388} and the principle upon which it works lies in the laws of motion (force(f) = mass(m) x acceleration(a)) and by using vibration one can improve stability, strength or power by either applying more mass or more acceleration to the body. Many forms of training and conditioning use mass such as weight machines and free weights. Vibrating machines, instead, use the second half of the equation by applying acceleration to the body, while keeping mass the same – "vibration makes the body feel as though it 'weighs' more every time acceleration forces increase" (www.powerplate.com). Vibration can increase gravitational load of up to 14g³⁸⁸ (where

$g=0.98\text{m.s}^{-2}$). This allows for optimal 'loading' for strengthening while reducing the effect of high impact and high stress factors.

Biological response to vibration

Exposure to vibration can affect the neuro-endocrine, cardiovascular, musculoskeletal and sensory systems. The effect of the mechanical action on the musculoskeletal system is to produce fast and short changes in the length of the muscle tendon complex which can elicit a tonic muscle contraction via the Tonic Vibration Reflex (TVR). The stretch and H-reflex are inhibited during exposure, while post exposure the stretch reflex displays increased potentiation. Recorded electromyography (EMG) activity of the biceps while exercising with vibrating dumbbells was 200% higher than when performing elbow flexion with a dumbbell with a mass of 5% of the subject's body mass³⁸⁰. Vibration is also perceived by the skin, the joints and secondary endings which all enhance the sensitivity of the primary endings³⁸⁹. It is also postulated that vibratory stimulation can influence central motor command is capable of producing a kinaesthetic illusion shown to activate the supplementary motor area and the caudal cingulate motor area. Furthermore vibration appears to inhibit activity of the antagonist altering the intra-muscular coordination patterns leading to decreased breaking force around the joints. However studies investigating the impact of these neurophysiologic changes on motor performance have found this effect to disappear within 60min³⁸². Vibration can also compensate for reduced motor output in a fatigued state as it compensates for decreased γ -motor neuron drive by exciting the Ia afferents which results in reflexive excitation of α -motor neurons and greater force output³⁹⁰.

The negative effects of vibration on the human body are also well documented but most commonly occur in the workplace³⁹¹ and sporting environment (alpine skiing and horseback riding for example) through exposure to large vibration loads and chronic exposure³⁹². The body's reaction to exposure however is dependent on the frequency, magnitude, duration and type of vibration³⁸⁷. The physiologic response to vibration is also variable and also depends on orientation of the subject (facing forwards or sideways), position of the subject (sitting or standing), body posture (stiff or relaxed) and is also affected by size, age, gender and psychological preparedness of the individual³⁸⁷.

Vibration training and equipment

Vibrations transmit waves of energy throughout the body, activating muscle contractions between 25 and 50 times per second, enhancing overall performance in sessions as short as 15 minutes a day, three times a week³⁸⁷. Several instruments such as vibrating pulley-systems and platforms are used for vibration training. Vibrating platforms are more commonly used for total body effect (also referred to as whole body vibration training) on which subjects can perform various static or dynamic exercises. Machines differ in terms of direction of vibration. Frequencies for training purposes vary between 25 and 50Hz and range in amplitude from 2 to 10mm.

Whole body vibration therapy and cerebral palsy

There is paucity in the literature regarding evidence for safe and effective use in children with or without pathology. An earlier investigation focussed on the effect of vibration on bone mineral density in children with 'disabling' conditions and the device used allowed for stationary standing on a vibrating platform only³⁹³. In adults with CP, a study by Ahlborg et al. (2006) compared vibration training with resistance training and reported WBV to increase strength and improve motor performance. It has been reported in adults that WBV does not appear to increase spasticity³⁸² nor result in any other detrimental adverse effects²⁵¹. The use of vibration in other areas of neurological pathology in adults has been studied and a systematic review which included persons with multiple sclerosis, Parkinson's disease and cerebral palsy suggest WBV therapy to be effective in improving balance and gait function and reducing risk of falling in the elderly³⁹⁴. It has also been the researcher's experience that standing on the vibration platform or doing exercise on the plate does not increase spasticity in adults with stroke. There is rather some suggestion that TBV can reduce spasticity, but this is yet to be demonstrated empirically.

6.2.3 Conclusion

There is some evidence for the impact of targeting the abdominal muscles on function in adults, however in children and within the CP population the evidence is limited to few studies with small sample sizes and varying outcome. The use of vibration to facilitate muscle contraction seems to be a safe and appropriate choice of intervention

for supplementing a strengthening exercise program targeting the abdominal muscles in children with CP given that these muscles are poorly activated and are deeply situated rendering typical manual facilitation techniques inadequate.

6.3 Research Question

What is the effect of a four-week trunk-targeted re-education and strengthening intervention on gait, posture, balance and abdominal thickness measurements in six to 13 year old children with spastic type diplegic and hemiplegic cerebral palsy?

6.4 Methodology

As previous studies on strengthening in children with CP have generally showed an improvement at impairment level in terms of increased strength, it was decided that the primary outcome measure of this study would be at the level of activity, specifically gait performance. A second primary outcome would be an alteration in muscles thickness as visualized using US imaging.

6.4.1 Study design

A single blinded experimental pre-post crossover study design with random assignment was used to investigate the effect of a trunk-targeted intervention in children with STCP (Table 38). For the current investigation a large standard deviation (SD) was expected within the sampled group for the primary outcome which was the distance walked in one minute. The availability of only a limited number of potential subjects further motivated the selection of the current design. This design allowed for comparison with a control group as well as preliminary investigation into the medium term effects following withdrawal of the intervention.

Table 38 Experimental crossover study design

Group 1:	M1	Intervention (4 weeks)	M2	No intervention (4 weeks)	M3
Group 2:	M1	No intervention (4 weeks)	M2	Intervention (4 weeks)	M3

M = measurement; M1 = baseline, M2 = at 4 weeks and M3 = at 8 weeks

6.4.2 Objectives

In a group of six to 13 year children with spastic diplegia or hemiplegia, this study aimed to determine the short term and medium term effects of a four week trunk-targeted intervention using whole body vibration on activity as measured by gait and balance analysis as well as on impairment, particularly posture and strength analysis. More specifically the primary objectives were to determine the effect on:

- gait (as determined by 1-min walk test)
- posture (upright posture and pelvic- and trunk position as determined by 2D photographic analysis)
- balance (as determined by the Paediatric Balance Scale)
- resting thickness of the four abdominal muscles (TrA, OI, OE, RA) in supine (as determined by ultrasound imaging (US))
- abdominal muscle strength (as determined by the no of sit-ups in one minute)

Secondary objectives were to determine the effect on:

- abdominal muscle activation patterns during head up activity in supine (US)
- abdominal muscle activation patterns during leg lift activity in standing (US)
- weight gain (scale)

6.4.3 Hypothesis

The first hypothesis for the current study is that there will be a significant difference at M2 between children who participated in the trunk-targeted exercise program (Group 1) and the children not receiving the intervention (Group 2) during this time (Table 38) and that the children receiving treatment will perform better at M2 than the non-intervention group. The second hypothesis is that there will be a significant improvement in performance in Group 2 from M2 to M3, while Group 1 will maintain the anticipated improvement from M2 to M3 but will not show any further improvement after the withdrawal of the intervention.

6.4.4 Subjects and sampling

The same 30 children who were invited to participate in the previous correlational study (Chapter 5, refer to 5.6.1) were also invited to take part in the current intervention

study. The names of those who agreed to participate and provided written informed assent (Appendix 4) and who parents gave written informed consent (Appendix 3) were listed and given code numbers. They were then randomly assigned to the different intervention groups using Excel generated random numbers (Table 38).

Inclusion criteria

To be included in the study, subjects had to meet the following criteria:

- be diagnosed by a paediatrician as having spastic diplegic or hemiplegic cerebral palsy
- be between the ages of six and 13 years
- be in good general health
- be ambulant - with or without walking aids, with or without orthoses (Gross Motor Function Classification Scale (GMFCS) I, II or III)
- be able to comprehend instructions in either English or Afrikaans

Exclusion criteria

Subjects were excluded from the study if:

- they presented with any other motor dysfunction or condition affecting motor performance (e.g. ataxia, spina bifida, muscular dystrophy etc.)
- had any orthopaedic surgery or spasticity altering procedures in the previous 12 months
- had a body mass index (BMI) > 25kg/m² (too much adipose tissue renders ultrasound imaging difficult and effects reliability³⁶⁴)

A sample size calculation was done using the 1-minute walking functional outcome measure of total distance walked in one minute. The following parameters were entered: mean 90m before treatment and 97.5m post-treatment²⁷³, a standard deviation (SD) of 10m before and after treatment, a significance level of .05 and a power level of 80%. As the small number of subjects available was unable to support a comparison independent t-test design, the sample size was calculated using a dependent t-test, i.e. comparing the performance of the children before and after treatment using a two tailed t-test (Statistica Version 9). This suggested a sample size of 29 subjects.

6.4.5 Procedure

Approval was obtained from the Research Ethics Committee at Stellenbosch University (N09/08/201), the Research Directorate from the Department of Education as well as the Headmaster of the participating school.

6.4.5.1 Instrumentation

Ultrasound imaging, the 1-Minute Walk Test, the Paediatric Balance Scale and 2-D photographic posture analysis was used to assess the effect of an abdominal muscle re-education and strengthening intervention on gait, balance, posture and muscle thickness during rest and activity. All of these outcome measures were selected for their clinically feasible application. Restricted time and access to research laboratories further prompted this selection. As the exercise program involved vibration technology using Power Plate® which is more typically known as a strengthening intervention³⁹⁵ the measurement of the total number of sit-ups in one minute was also recorded to estimate the impact on abdominal muscle strength.

Measurement of demographic characteristics

Baseline demographic variables - age and level of functioning according to the GMFCS⁵, use of walking aids and or orthoses - were recorded onto an excel spreadsheet. Height was measured using a standard tape measurement fixed to a wall (refer to 5.3.3). Weight was measured using a calibrated digital SALTER Personal Fitness Plus Scale (UK) (model 9191). Participants were asked to undress down to shorts/skirts and vests before being weighed.

Ultrasound imaging (US)

The thickness of the four abdominal muscles - TrA, IO, OE and the RA - were recorded and measured, using a Siemens® Accusonic X150 ultrasound imaging machine with a 5.5cm wide band linear array frequency of 5Hz. B-mode (2-D). Real-time images of the right side in children with diplegia and the affected side in children with hemiplegia of the four abdominal muscles were captured (refer to 3.3.3.4 and 4.3.4.1).

Resting thickness was recorded as it is hypothesized that an increase in strength may be accompanied by an increase the size of the muscle⁶⁸. Analysis of the percentage change in thickness of the abdominal muscles during activity may provide pertinent

information regarding change in patterns of recruitment of the stabilizing and mover muscles (for e.g. RA activity vs. TrA and OI activity) and was therefore conducted in the current study.

The 1-minute Walk Test

The fast 1-minute walk test as described by McDowell et al. (2005) was used as a measurement of functional ability and measures the distance a child is able to walk in one minute (refer to 5.3.3.1) .

Digital Photographic 2-D Postural analysis

A high speed digital camera (Canon 40D) was used to capture static standing and kneeling posture as viewed from the side. Similarly a lateral view of seating posture was also captured. Images were downloaded to a personal computer (PC) and using Image J software (refer to 5.3.3.1) the degree of antero-posterior pelvic tilt and forward trunk sway was measured as well as shoulder-to-sitting/kneeling surface height. Although the information obtained using 2-D analysis is limited, stringent standardisation of the procedure can produce reliable measurements to determine kinematic variables^{366;367} .

The current study hypothesized that an increase in abdominal muscle strength will result in a reduced anterior tilt (typically seen in children with STCP) which in turn will allow for a more upright posture and was therefore measured using digital photographic imaging.

Paediatric Balance Scale (PBS)

The PBS²⁸⁹ is a modified version of the Berg Balance Scale (BBS). Franjoine et al. (2003) adapted the BBS - a standardized outcome measurement used for the assessment of balance particularly in the elderly with or without pathology²⁸⁶⁻²⁸⁸ - for school-aged children by reducing the time for maintaining static postures, reshuffling of the order of the tasks and adapting the task instructions without altering the demands of the task. The test consists of 14 items ranging from sit to stand to reaching forward with outstretched arm and includes activities such as tandem standing, standing on one leg and picking up an object off the floor. Each item is ranked between 0 – 4 (Appendix

5). Typically developing children between the ages seven to 15 can successfully complete all items and can obtain a maximum score of 56²⁸⁹.

The PBS test can be conducted at the school and only takes ± 15 minutes to complete. Force plate data, other lab based tests and the typical time static balance activities have shown better reliability²⁸⁵, but only measurement level of impairment (refer to 2.6.1.2). As the PBS is aimed to determine a child's functional balance ability in activities of daily living it was deemed an appropriate outcome measurement for investigating the effect of the trunk-targeted intervention on balance function as it was hypothesized that improved core activity will impact balance.

Sit-ups in one minute

The total number of sit-ups executed in one minute was selected to measure effect on abdominal muscle strength. Although not a standardized outcome measure, this field performance measure is well used in research to reflect possible strength gains in the abdominal musculature³⁰³.

Although the primary aim of the selected trunk-targeted intervention is to activate or re-educate the abdominal stabilisers, strengthening was likely to occur and to investigate this effect on these muscles it was deemed appropriate to include this outcome.

6.4.5.2 Pilot study and reliability testing

Tester reliability for the 1-minute Walk Test, sit-ups in one minute and the angle measurements for the 2-D photographic imaging for the posture analysis was demonstrated in an earlier study (Chapter 4). Similarly reliability for thickness measurements using US imaging was also determined (Chapter 3). For the current study tester reliability for the PBS and length measurements used for posture analysis were conducted on ten randomly selected participants from the control group. Repeated measurements by the same tester either on the same day or between days was conducted as described in the testing procedures below for each of the above measures. Table 38 shows a complete listing of the Intra-class Correlation Coefficient (ICC) scores for all variables measured in the current study.

Table 39 Intra-tester reliability of outcome measurements: distance walked in 1min, no of sit-ups in 1min and degree of pelvic tilt, a-p angle and shoulder-to-floor height measurements (2D-imaging) and PBS (Intra-class Correlations Coefficients) (n=10)

Outcome measurement	ICC	95% Confidence Interval	SEM
1 min walk test	0.979	0.910 ; 0.994	2.403
no. of sit-ups in 1min	0.990	0.972 ; 0.997	1.085
degree of a-p pelvic tilt	0.982	0.939 ; 0.994	0.749
a-p angle	0.947	0.843 ; 0.983	2.394
shoulder-to-floor height	0.905	0.738 ; 0.968	17.039
PBS	0.981	0.938 ; 0.994	1.637

Procedures, as described in the literature for each outcome were followed. No amendments were necessary and the procedures as described below were ultimately followed in the current study.

As the exercise program was a novel approach to trunk-targeted intervention, children with STCP – those not selected for participation in the current study i.e. older children or those who had undergone surgical procedures in the 12months prior to the study – assisted the researchers to refine the exercise regime that was followed in the current study.

6.4.5.3 Testing procedure

All the measurements were taken at the school during school hours. Tests were conducted over a two day period in no specific order - two tests on day one and the remaining two outcomes measured on day two. This was to ensure sufficient rest between tests and to limit time out of the classroom. As sufficient rest between tests was insured, it was presumed the order of testing would not influence outcome.

The primary investigator conducted the balance, 1-minute fast walking test and photographic posture analysis. A research assistant conducted the US imaging and measurement. All four measurements were taken by the same tester at baseline (M1), four weeks (M2) and again at eight weeks (M3). The primary investigator was blinded as to which subjects participated in either of the two arms of the study.

Ultrasound imaging (US)

The same protocols for capturing images in the supine and standing positions as described in Chapters 3 and 4 were followed in the current study. Images were captured both at rest and during contraction. In the supine position the head lift activity (refer to 3.3.3.4) and in standing lifting of the contra-lateral leg to the side being captured (refer to 4.3.4.1) was used for images taken during contraction. For the first set of images subjects were positioned in supine followed by the second set of images which were captured while standing between parallel bars.

The 1-minute Walk Test

Similarly the same protocol was followed as described in Chapter 4 (4.3.4.3). For this measurement, participants were asked to walk as fast as they can on a marked oval level course for exactly one minute. The distance covered was recorded. Participants using splints and or walking aids were permitted to use them during this test. A trial run is recommended²⁸⁹ and was done with a five to ten minute rest before the main trial commenced.

2-D Posture analysis

For the analysis of posture three photographs were taken and stored for analysis - one in sitting, one in kneeling and one photograph in standing (Figure 26). Wearing only under garments, eleven reflective markers (from the VICON Motion Analysis System) were placed on the following bony points (Figure 26):

- temporomandibular joint (TMJ)
- C6
- the superior border of the manubrium
- mid-point on the lateral border of the acromion
- posterior superior iliac spine (PSIS)
- anterior superior iliac spine (ASIS)
- the sacrum
- greater trochanter
- lateral epicondyle
- lateral malleolus and
- lateral aspect of the head of the 5th metatarsal bone

Subjects were asked to stand as upright as possible and a lateral image, from the right only or in children with left-sided hemiplegia, from the left only, was captured. Similarly participants were asked to sit on a dense foam block and kneel on a mat - as upright as possible - and images captured. Images were downloaded onto a PC for analysis later.

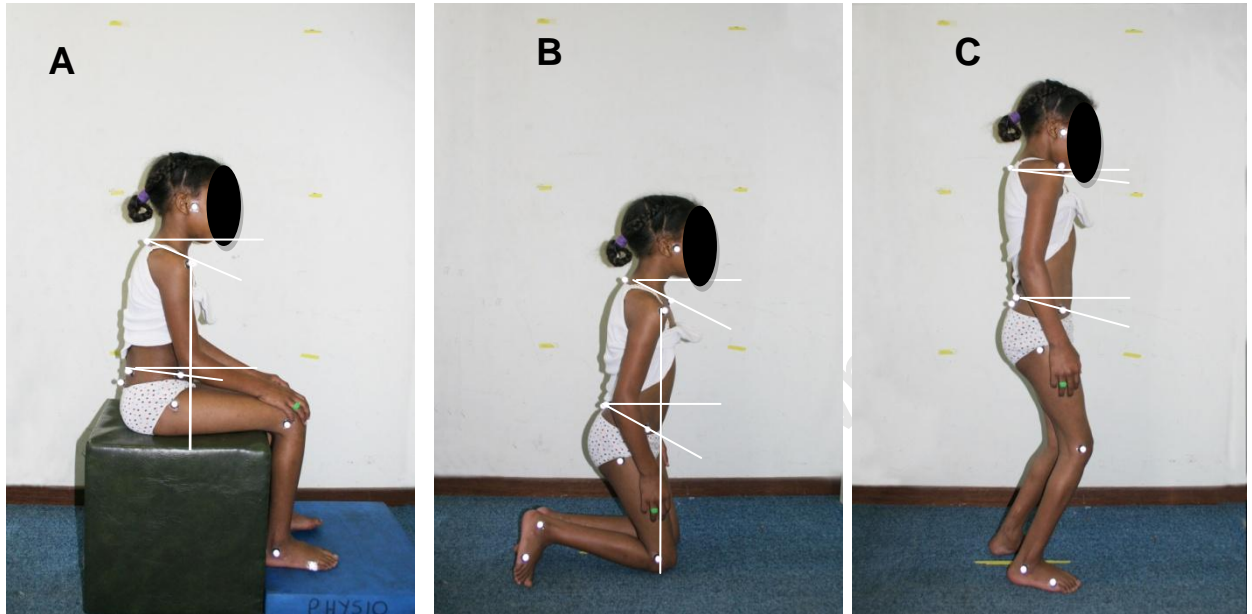


Figure 26 The three positions photographed for posture analysis – A: sitting; B: kneeling; C: standing

To ensure repeatability of the measurement:

- the camera was mounted on a tripod 130cm from the ground and
- positioned exactly 2.5m away from the opposite wall
- the camera was positioned to capture portrait style photographs
- and the settings recorded to be repeated at each measurement session
- markings on the wall at 50cm, 100cm and 150cm, 500cm wide formed a frame in which the children were positioned
- subjects stood with one foot or knelt with one knee on each side of a line 30cm from and parallel to the wall (Figure 26B,C)
- for the sitting position, subjects sat on a foam block placed exactly in the middle over the same line (Figure 26A)
- subjects were asked to stand, kneel or sit as upright as possible, look straight ahead
- in sitting subjects had to rest their hands on their knees (Figure 26A)
- no physical or verbal posture correction was done

- for subjects requiring support in standing, one hand on the wall was permitted, was recorded and had to be used in M2 and M3
- similarly if subjects were unable to kneel independently, bilateral arm support, by holding on to a small chair was allowed and recorded to be repeated at M1 and M2

Paediatric Balance Scale (PBS)

This test was conducted in the physiotherapy gymnasium as described by Franjoine et al. (2003). All 14 items (Appendix 5) were set up and subjects completed each task before moving on to the next task. Two trial attempts were permitted and the performance of the final execution was recorded. Splints and shoes were worn, but no walking aids were permitted.

Sit-ups in one minute

In the crook lying position with the feet supported by the research assistant, subjects had to sit-up or curl-up to 90° hip flexion without arm support and return to the almost flat (flat hand) supine position as many times as they could in one minute.

6.4.6 Intervention

A selective trunk targeted exercise program using the Power Plate® (vibration technology) (Figure 25) was used to activate and strengthen the abdominal musculature in this study. Although a novel form of exercise in this population, the underpinning theory regarding involuntary capacity to activate weak or dormant muscle, it was deemed appropriate to use vibration technology to target the abdominal muscles in children with spastic cerebral palsy. Further benefits for using vibration technology is the 'ease' of use – no external resistance, i.e. no heavy weights necessary and only one set of repetitions are required vs. three times ten repetitions recommended in the strengthening or weight training (PRE) literature⁶⁸, allowing for a total five to ten minute workout session instead of 30 – 60min gym workout session.

Although the program was self-compiled, all exercises were selected based on evidence of their efficacy for strengthening of both concentric and isometric contraction

reported in the literature^{25;96;291;370;377;378;396}. The probability of self-execution was also taken into account, although some of the exercises such as the abdominal crunch may have needed external support / assistance.

Although the findings of the previous studies primarily suggest poor stabilising function - i.e. poor TrA and OI activity - children with STCP also presented with significantly thinner RA muscles when compared with children with TD. Three of the eight exercises (crunches, cycling and hand-behind-head) demanded increased RA activity. Of those exercises only crunches and cycling recruit RA as mover muscle. During cycling and hand-behind-head however the oblique muscles are the primary targeted muscles, while RA and TrA function as stabilisers.

All the exercises including the warm-up were conducted on the vibrating platform. All participants completed the following exercise program:

- 45sec warm-up: standing
- 4 x 30sec various sit-up exercises in supine on a cushion (crunches, cycling, hand behind head and table top) (Figure 27a and d)
- 1 x 30sec hip and lumbar extension exercise in four point kneeling or prone over a ball
- 2x 30sec side lying crunches (Figure 27c)
- 1x 30sec plank (Figure 27b)

The above 5-10min exercise session was introduced as follows:

3x in week 1; 4-5x in week 2; 5x in weeks 3 & 4

This allowed for the recovery of possible delayed onset muscle soreness. Power plate is a novel activity for this particular group of participants and some experienced some muscle soreness initially. Exercises were progressed by increasing the time to 45sec and eventually 60sec per exercise. No additional exercises, external resistance or equipment was used.

These sessions all occurred during their usual therapy sessions or during break-time. All other therapy - Occupational Therapy or Speech Therapy - continued as per usual. The sessions were all supervised by a qualified physiotherapist^{xv}.



Figure 27 Examples of abdominal muscle targeted exercises: (a) abdominal crunches; (b) plank (c) side crunches and (d) hand behind head twist

While typically the duration of an exercise program spans six to eight weeks, the number of training sessions is limited to 2-3 times per week. However in the current study as from week two participants were subjected to the training sessions on a daily basis. This allowed for a total of 18 - 20 exercise sessions which according to the American College of Sports Medicine is the minimum required exposure to allow significant increase in strength to occur (American College of Sports Medicine, 1998). A further motivation for the 4 week (x2) approach was logistical in that the school term was only nine weeks long, ensuring an uninterrupted study/intervention-and-testing period.

^{xv} Research assistant and not a therapist employed at the participating school

6.4.7 Measurement and Data Processing

The data for each outcome measure was processed as follows and entered into an Excel spread sheet for statistical analysis:

6.4.7.1 US imaging

Machine cursors were used to measure muscle thickness in millimetres (mm) within the fascia boundaries as described by Ferreira et al. (2004) (refer to 3.3.4). Three measurements were taken for TrA, OI and OE at 10mm, 15mm and 20mm from the medial edge of the TrA. The average of each of the three measurements was recorded for analysis. Similarly three measurements were taken for RA at 10mm, 15mm and 20mm from the medial border and averaged⁷⁸.

6.4.7.2 1-Minute Walk Test

The distance covered during the final 'round' was recorded in meters.

6.4.7.3 2-DPosture analysis

All images were downloaded onto a personal computer (PC). Using Image J software, from the images captured in standing the following angles were measured: antero-posterior (a-p) angle – the angle between lines drawn from the marker positioned on C6 posterior and the sternum anterior and a horizontal line from C6; and a-p pelvic tilt – angle formed between a line which runs through the posterior and anterior superior iliac spines and the horizontal (Figure 26). Although measurements for hip, knee and ankle angles were envisaged at the start of the trial, these angles were not measured for any of the three positions. For the kneeling and sitting images the above angles were measured as well as the distance from the marker on the acromion to the seating surface (sitting) or to the floor (kneeling) (Figure26).

For the a-p angle, it is assumed that the smaller the angle, the more upright the posture in relation to the pelvis (i.e. less crouched or less forward leaning) and a negative value is indicative of an over extended upper trunk. Similarly for the pelvic tilt measurement, the smaller the angle the more neutral the pelvis is positioned and a negative value suggests a posterior pelvic tilt. In sitting a more neutral pelvis suggest a more upright posture. Similarly in kneeling, it can be assumed that the smaller the pelvic angle the more upright the posture.

6.4.7.4 Paediatric Balance Scale (PBS)

Items were scored and totals calculated. For some of the items opportunity is afforded to document time for execution (Appendix 5), but these recordings were not further investigated by the current study.

6.4.7.5 Sit-ups in one minute

The total number of sit-ups executed in one minute was recorded.

6.4.8 Statistical analysis

Statistica (Version 9) was used to analyse data. A one way analysis of variance (ANOVA) was used to test the effect of randomization at pre-intervention using the M1 measurements of the two groups to establish if the two groups were equivalent. Although not relevant to the analysis of the outcome, the Chi-squared test and Fisher two-tailed exact t-test were used to compare the two groups with respect to diagnosis and gender respectively to ensure complete reporting. Kolmogorov Smirnov tests were also done at M1 and M2 to inspect distribution of the values of all the variables measured. For the other demographic characteristics – age, height, weight and BMI - t-tests for independent variables were used to compare the two groups where the distribution of the values for those variables showed normal distribution. In cases where no normal distribution was found, the Mann Whitney-U test was used.

Using repeated measures ANOVA - using a mixed model approach³⁴⁶ -measurements at M2 were compared to determine if participation in a four-week exercise program had an impact on the following variables: balance, posture, gait and abdominal muscle thickness. The change between M2 and M3 was also examined to establish if Group 1 remained the same and whether Group 2 improved over this period.

Fisher least significant difference (LSD) post-hoc tests were also done to inspect the data further and to determine the level of significance at the various time points. A 5% significance level ($p < 0.05$) was used as guideline for determining significant differences. Where the time*group; LS means (ANOVA) was not significant i.e. where there was no significant difference over time between the two groups ($P > 0.05$), but where visual inspection suggest a possible effect from pre- to post intervention within each group, two time point ANOVA was conducted. The data of Group 1 from pre- to

post intervention (M1-M2) was combined with the data of Group 2 from pre- to post intervention (M2-M3) and the total effect was determined.

The ANOVA results are displayed in graph format. Significant letters are used on the graph to indicate significant difference on a 5% level. A significant difference is indicated where there are no similar letters when comparing two points. Furthermore, where the time*group analysis suggests significant difference between the two groups, tables have been used to display the outcome within each group for following time points (M1-M2), (M2 – M3) and (M1 – M3). Means and standard deviations (SD) for the variables measured as well as the mean difference and SD between the two measurements for each group was tabulated.

6.4.9 Ethical considerations

The basic ethical principles of respect, autonomy, beneficence and non-maleficence were addressed as follows:

Permission was sought from the Research Ethics Committee at Stellenbosch University and from Western Cape Education Department to conduct the study at the school. Informed consent was obtained from parents and or legal guardians of all potential participants and informed assent from all those participants was sought. Participation was entirely voluntary and refusal or discontinuation did not affect standard treatment. Children and parents had the right to withdraw at any time without it affecting current therapy management at the school. All other therapy - Occupational Therapy and or Speech Therapy - was continued as per usual.

Anonymity and confidentiality was assured to all participants. All personal information would be used solely by the research staff and should there be any publications, the participant's identity will not be disclosed. Consent to use any photographs taken during testing or participation in any presentations or publications will be separately obtained from parents and participants – faces of the children will be made unrecognizable and parents or legal guardian and the child will be asked to sign the back of the photograph if they both agreed to the use thereof. Photographs not selected for publication or academic presentation purposes will be destroyed following completion of the main study.

Potential benefits and risks were disclosed or discussed with both children and parents. The results will be made available to the therapists at Eros School, and to the parents upon request. In case of accidental injury during testing or as a result of the exercise program, a registered nurse or doctor was available at the school.

Although the principle of justice may have been violated in that children from only one school - a traditionally disadvantaged or of lower socio-economic standing – were selected for participation, no harms, only potential benefit was envisaged for these children. Furthermore continued access to the intervention under investigation was negotiated with Power Plate® SA in that ongoing studies into vibration technology would be supported by the company.

Although the study utilizes a sample of convenience and is limited to children with spastic type CP, the results are generalisable to all children with STCP and may well be applicable to a wider spectrum of children with motor dysfunction.

6.5 Results

Description of the sample's demographic characteristics and analysis of the effect of randomization (Group 1 vs. Group 2) will precede a report of the findings regarding the short and medium term effects of the four week trunk-targeted exercise intervention. Where post-hoc analysis suggests a possible significant trend, two time-points ANOVA analysis (i.e. pre-post effect for the total group) is reported.

6.5.1 Subject demographic characteristics

Thirty informed consent forms were handed out to learners at the school and 27 subjects were ultimately recruited into the study. The parents of three potential subjects did not consent to participation (Figure 28). There were 17 males and ten females enrolled. Fifteen subjects were diagnosed with spastic diplegia, nine presented with right hemiplegia and three subjects with left hemiplegia. The numbers relating to gender and type of cerebral palsy were evenly distributed between the two groups (Table 40).

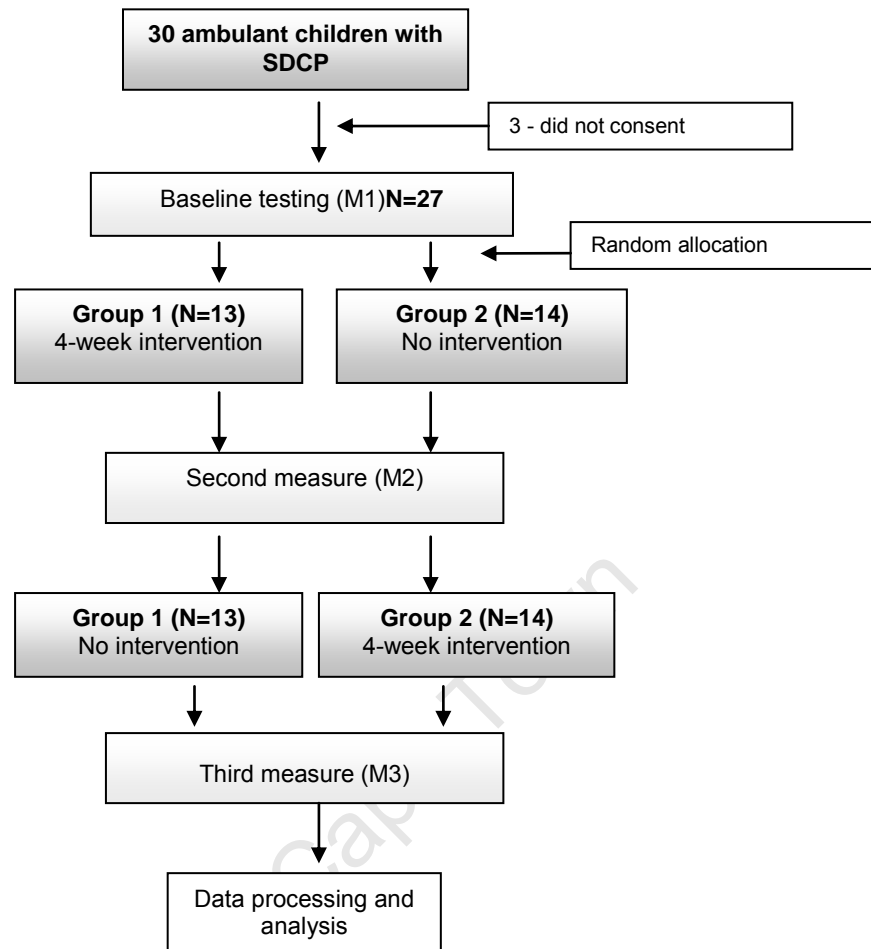


Figure 28 Study design: Intervention study

Table 40 Distribution of gender and type of CP

GENDER	Group 1	Group 2	Total	DIAGNOSIS	Group 1	Group 2	Total
Female	7	3	10	Hemiplegia	6	6	12
Male	6	11	17	Diplegia	7	8	15
Totals	13	14	27	Totals	13	14	27

Fishers exact two tailed test $p=0.120$

Chi² test $p=0.863$

There was a normal distribution for the values recorded for height, weight and BMI within each group (Table 41). Group 1 had a skewed distribution for age which ranged between 10.5 to 13.8 years (median = 13.1).

Table 41 Descriptive statistics for age, height weight and BMI and comparison of distribution between groups

	Group 1				Group 2				Gr 1 vs. Gr 2	
	Mean	SD	Norm. (SW)	Norm. p	Mean	SD	Norm. (SW)	Norm. p	t-value	p
age (yrs)	12.39	1.33	0.84	0.019	10.49	2.02	0.89	0.069		0.009*
height (m)	1.47	0.07	0.953	0.637	1.37	0.12	0.946	0.503	-2.585	0.016
weight (kg)	34.24	7.58	0.934	0.386	32.30	7.32	0.962	0.763	-0.678	0.504
BMI (kg/m²)	15.71	2.35	0.937	0.416	17.17	2.95	0.950	0.564	1.423	0.167

Norm = normality; SW = Shapiro-Wilks, * Mann-Whitney U test

In summary, participants in Group 1 were significantly older and taller than participants in Group 2 (Table 41). Although the difference between the two groups was not significant and despite being younger and shorter, subjects in Group 2 were slightly heavier for size (Table 41) than subjects in Group 1.

Table 42 presents a description of the groups GMFCS levels and use of orthoses. Five of the six participants in GMFCS III required walking aides.

Table 42 Description of level of functioning and use of orthoses and walking aids

	Group 1	Group 2
GMFCS I	7	6
II	4	4
III	2	4
single AFO	0	1
bilateral AFO's	1	0
crutches	0	1
rollator/K-walker	1	3

(GMFCS - Chi² test p=0.698)

6.5.2 Effect of intervention on gait

The values of distance walked in one minute were normally distributed at M1 and M2 within each group (Table 43). At baseline (M1) there was no statistically significant difference between the two groups ($p=0.4$).

Table 43 Descriptive statistics for distance (m) walked in one minute for each group at M1 and M2 and comparison between groups at M1.

Measurement	Group 1				Group 2			
	Mean (m)	SD	Norm (SW)	Norm p	Mean (m)	SD	Norm (SW)	Norm p
1_distance (m)	94.74	26.28	0.933	0.333	87.03	20.07	0.910	0.181
2_distance(m)	106.70	23.56	0.9316	0.991	88.58	19.58	0.930	0.306

SW = Shapiro-Wilks; * $p<0.05$

The results of the repeated measurements ANOVA are shown in Figure 29. There was a significant interaction between group and time ($p<.001$) and the results of the post-hoc analysis as reported in Table 44 indicate there was a significant difference between the mean values of Group 1 before and after intervention and similarly between the means of Group 2 from M2 and M3, during which intervention had been applied. However a significant difference was again found in Group 1 between M2 which was higher and M3 which was lower and no significant difference between M1 and M3 in this group which indicate that the treatment effect was not sustained after the intervention was withdrawn.

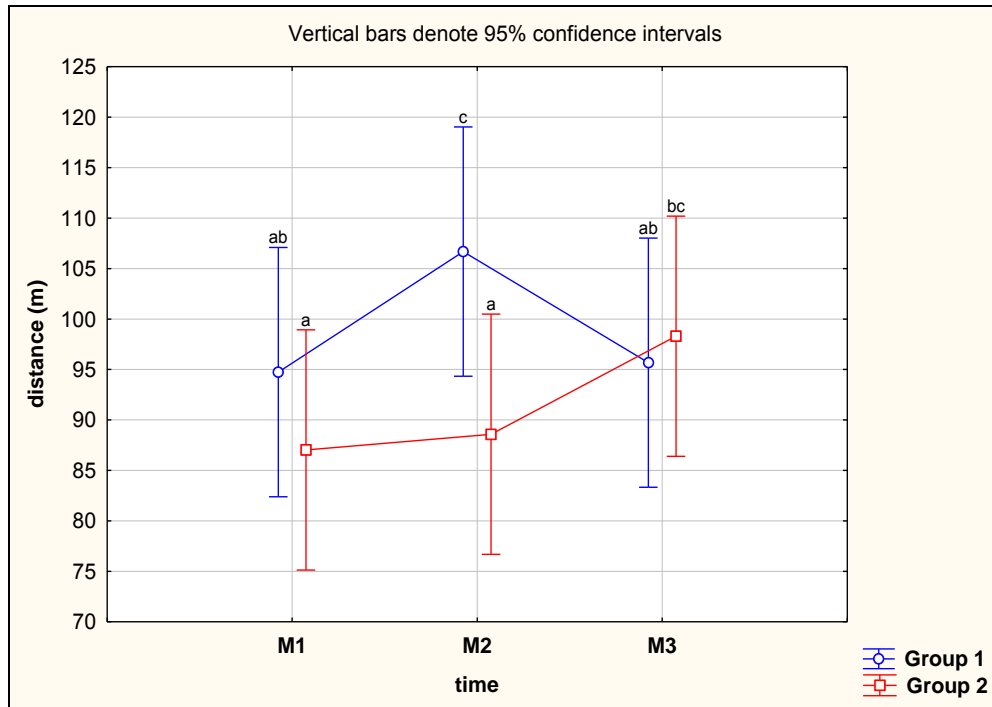


Figure 29 Effect of the trunk-targeted intervention on distance walked in one minute: time*group; LS means ($p < 0.000$)

Table 44 Intra-group analysis – M1-M2; M2-M3; M1-M3 for distance walked in one minute (m)

Measurement		Mean	SD	N	Diff.	SD	p
Group 1	1_distance (m)	94.74	26.28				
	2_distance (m)	106.68	23.56	13	-11.95	15.43	<0.001*
Group 2	1_distance (m)	87.03	20.07				
	2_distance (m)	88.58	19.58	14	-1.556	2.74	0.613

Measurement		Mean	SD	N	Diff.	SD	p
Group 1	2_distance (m)	106.68	23.56				
	3_distance (m)	95.68	22.64	13	11.008	11.32	0.001*
Group 2	2_distance (m)	88.58	19.58				
	3_distance (m)	98.30	20.62	14	-9.709	8.07	0.003*

Measurement		Mean	SD	N	Diff.	SD	p
Group 1	1_distance (m)	94.74	26.28				
	3_distance (m)	95.68	22.64	13	-0.938	17.30	0.768

6.5.3 Effect of intervention posture

Normal distribution at M1 and M2 within each group was found for most of the values of the variables measured to determine effect on posture except for the sitting pelvic tilt (Table 45). At M1 the two groups were similar with regard to all variables and no significant difference was detected between them for any of the variables measured.

Table 45 Descriptive statistics for variables measured for posture analysis for each group at M1 and M2.

Measurement		Group 1				Group 2			
		Mean	SD	Normality (SW)	Norm p	Mean	SD	Normality (SW)	Norm p
sitting	1_a-p angle(°)	31.03	8.45	0.963	0.826	23.32	10.68	0.965	0.829
	2_a-p angle(°)	26.17	6.83	0.918	0.203	26.71	7.90	0.924	0.282
	1_pelvic tilt(°)	2.91	9.59	0.839	0.027*	-1.05	7.83	0.869	0.051*
	2_pelvic tilt(°)	4.03	5.94	0.965	0.810	3.33	6.70	0.980	0.981
	1_acromion height(mm)	602.99	59.88	0.877	0.066	606.17	51.29	0.942	0.523
	2_acromion height(mm)	633.18	45.24	0.973	0.912	575.87	64.48	0.938	0.427
kneeling	1_a-p angle(°)	22.47	8.92	0.963	0.824	14.38	13.51	0.961	0.774
	2_a-p angle(°)	19.44	8.83	0.970	0.883	20.16	8.19	0.887	0.090
	1_pelvic tilt(°)	28.41	13.21	0.959	0.774	25.23	5.71	0.946	0.533
	2_pelvic tilt(°)	23.24	10.04	0.926	0.272	31.22	8.33	0.970	0.893
	1_acromion height(mm)	962.92	65.53	0.928	0.356	919.14	87.07	0.919	0.241
	2_acromion height(mm)	989.83	74.69	0.919	0.211	896.68	102.02	0.926	0.305
standing	1_a-p angle(°)	24.73	7.19	0.909	0.207	19.45	6.70	0.919	0.243
	2_a-p angle(°)	19.18	7.86	0.881	0.060	22.15	6.73	0.957	0.710
	1_pelvic tilt(°)	19.63	6.29	0.926	0.341	18.81	5.47	0.950	0.593
	2_pelvic tilt(°)	17.23	7.02	0.946	0.500	22.21	6.61	0.963	0.803

SW = Shapiro-Wilks; * $p < 0.05$

6.5.3.1 Sitting posture: a-p angle

Normal distribution at M1 and M2 within each group was found for the values of the sitting a-p angle (Table 45). The results of the repeated measures ANOVA are shown in Figure 30. There was a significant interaction between group and time ($p < .01$) and the results of the post-hoc analysis as reported in Table 46 indicate there was a significant difference between the mean values of Group 1 before and after intervention and similarly between the means of Group 2 from M2 and M3, during which intervention had been applied. No significant difference was found in Group 1 between M2 and M3. However a significant difference between M1 and M3 in this group was found suggesting that this group maintained their upright sitting posture even after withdrawal of the intervention.

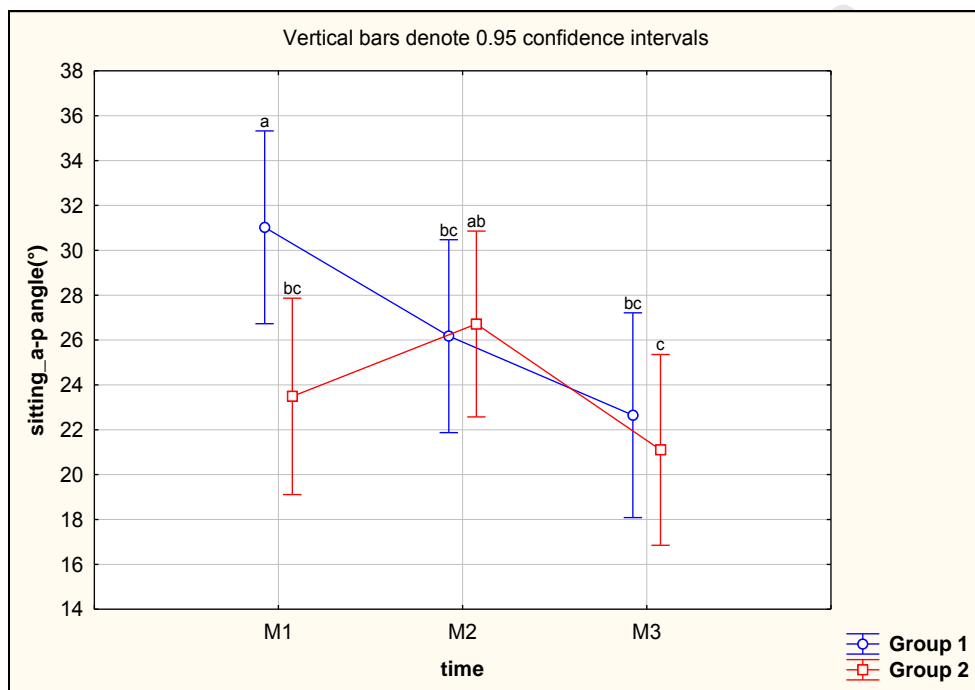


Figure 30 Effect on a-p angle in sitting: time*group; LS means ($p=0.038$)

Table 46 Intra-group analysis – M1-M2; M2-M3; M1-M3 for sitting a-p angle (°)

Measurement		Mean	SD	N	Diff.	SD	p
Group 1	1_sitting_a-p angle(°)	31.03	8.45				
	2_sitting_a-p angle(°)	26.17	6.83	13	-4.853	5.867	0.032*
Group 2	1_sitting_a-p angle(°)	23.32	10.68				
	2_sitting_a-p angle(°)	25.54	7.90	12	2.227	8.084	0.155

Measurement		Mean	SD	N	Diff.	SD	p
Group 1	2_sitting_a-p angle(°)	26.28	7.35				
	3_sitting_a-p angle(°)	22.24	6.03	11	-4.044	9.399	0.137
Group 2	2_sitting_a-p angle(°)	26.91	8.19				
	3_sitting_a-p angle(°)	21.58	5.04	13	-5.327	7.772	0.013*

Measurement		Mean	SD	N	Diff.	SD	p
Group 1	1_sitting_a-p angle(°)	29.63	7.63				
	3_sitting_a-p angle(°)	22.24	6.03	11	-7.394	8.154	<0.001*

* $p < 0.05$

6.5.3.2 Sitting posture: pelvic tilt

Although not significant, the change seen in Group 2 between M1 and M2 suggest lack of stability of this variable over time. Furthermore the values for the measurements for this variable in sitting did not have a normal distribution in either group at M1 (Table 45) although the two groups did not differ significantly from one another ($p=0.27$). The results of the repeated measures ANOVA (Figure 31) show that there was no significant interaction between group and time ($p>0.05$). The results of the two time-points analysis (total group effect) also showed no significant change from pre to post intervention ($p=0.225$).

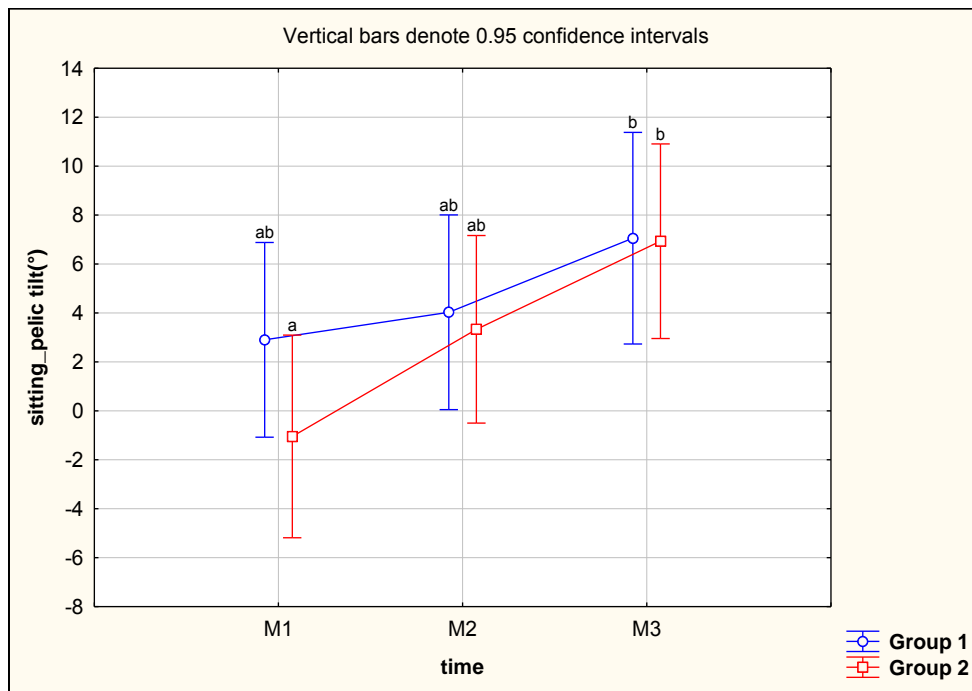


Figure 31 Effect on sitting pelvic tilt: time*group; LS means ($p=0.596$)

6.5.3.3 Sitting posture: shoulder-to-seat height

The values for the length measurements for the shoulder-to-seat height at M1 and M2 for both groups were normally distributed (Table 45). The results of the repeated measures ANOVA are shown in Figure 32. There was a significant interaction between group and time ($p<.01$) and the results of the post-hoc analysis as reported in Table 47 indicate there was a significant difference between the mean values of Group 1 before and after intervention and similarly between the means of Group 2 from M2 and M3, during which intervention had been applied. A significant increase was again found in Group 1 between M2 and M3 which indicate that the treatment continued to affect this variable even after the intervention was withdrawn. At M2 Group 2 showed a significant decrease in shoulder-to-seat height suggesting a more slumped posture. Stability of this variable is also questionable.

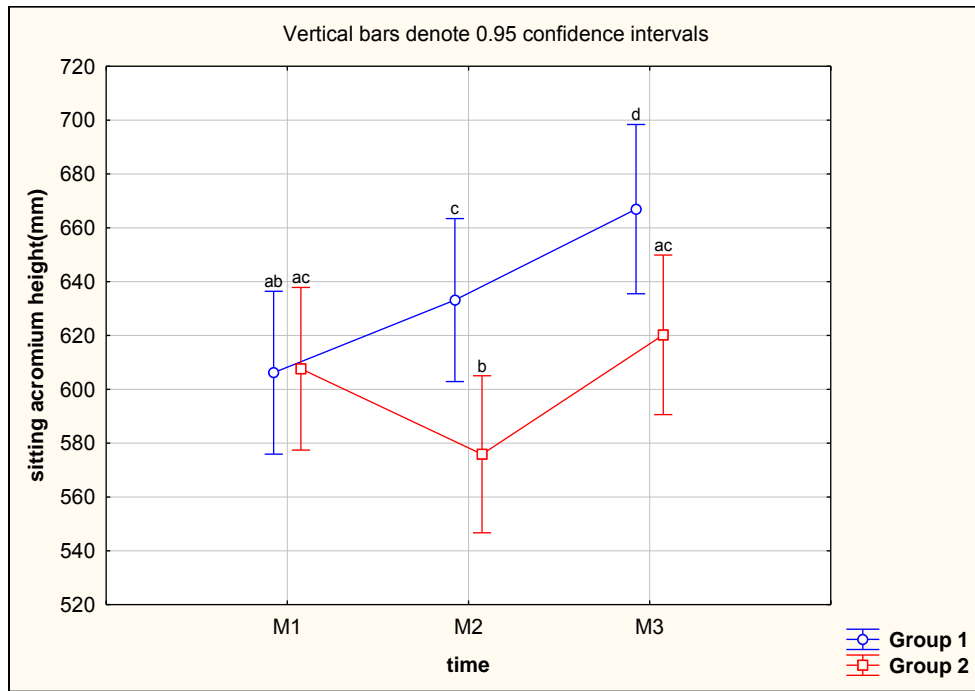


Figure 32 Effect on shoulder-to-seat height: time*group; LS means ($p=0.0027$)

Table 47 Intra-group analysis – M1-M2; M2-M3; M1-M3 for sitting shoulder-to-seat height (mm)

Measurement		Mean	SD	N	Diff.	SD	p
Group 1	1_sitting acromion height(mm)	606.17	51.29				
	2_sitting acromion height(mm)	633.18	45.24	13	27.01	24.82	0.027*
Group 2	1_sitting acromion height(mm)	602.99	59.88				
	2_sitting acromion height(mm)	571.24	68.47	12	-31.75	47.59	0.012*

Measurement		Mean	SD	N	Diff.	SD	p
Group 1	2_sitting acromion height(mm)	626.85	45.79				
	3_sitting acromion height(mm)	661.14	53.69	11	34.30	41.99	0.010*
Group 2	2_sitting acromion height(mm)	580.86	64.24				
	3_sitting acromion height(mm)	622.30	49.45	13	41.44	40.74	<0.001*

Measurement		Mean	SD	N	Diff.	SD	p
Group 1	1_sitting acromion height(mm)	598.31	51.19				
	3_sitting acromion height(mm)	661.14	53.69	11	62.83	44.63	<0.001*

* $p<0.05$

6.5.3.4 Kneeling posture: a-p angle

The values for the a-p angle measurements at M1 and M2 for both groups were normally distributed (Table 45). The results of the repeated measures ANOVA are shown in Figure 33. Despite significant interaction between group and time ($p < .05$) the results of the post-hoc analysis detected no significant difference between the mean values of Group 1 before and after intervention ($p = 0.176$) and similarly between the means of Group 2 from M2 and M3 ($p = 0.092$), during which intervention had been applied. There was however a significant decrease in this variable for the total group from pre- to post intervention ($p = 0.034$). The significant increase in a-p angle in Group 2 at M2 also questions stability of this variable.

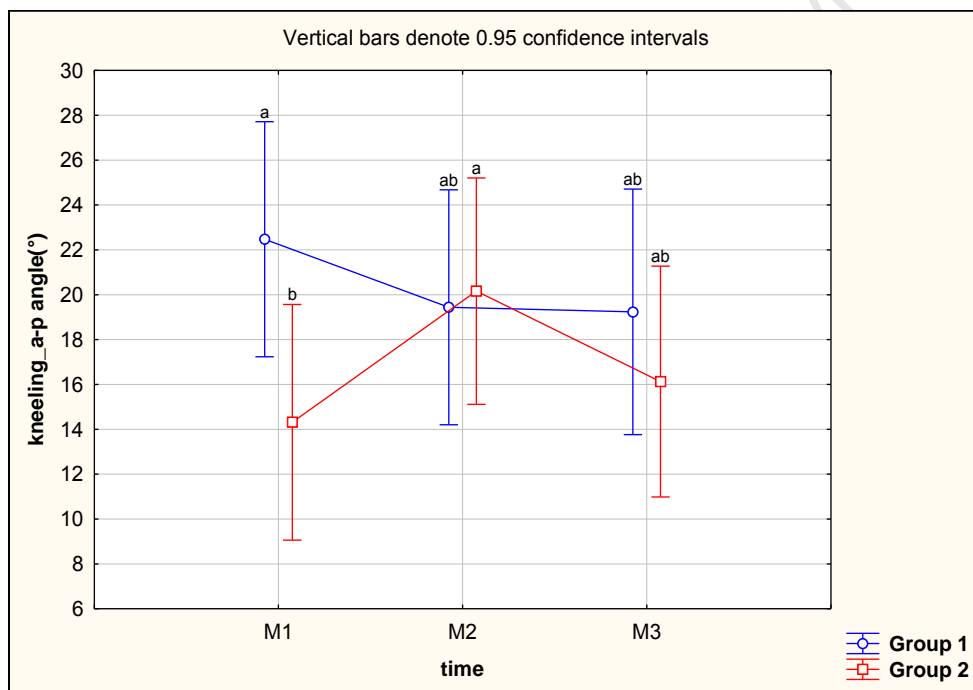


Figure 33 Effect on kneeling a-p angle: time*group; LS means ($p = 0.025$)

6.5.3.5 Kneeling posture: pelvic tilt

Values for the degree of pelvic tilt were normally distributed at M1 and M2 in both groups (Table 45). The results of the repeated measures ANOVA are shown in Figure 34. There was a significant interaction between group and time ($p < .01$) and the results of the post-hoc analysis as reported in Table 48 indicate there was a significant difference between the mean values in Group 1 before and after intervention. A smaller

decrease in pelvic tilt was recorded for Group 2 from M2 and M3, during which intervention had been applied. No significant difference was found in Group 1 between M2 and M3 but there was a significant difference between M1 and M3 which indicates that the treatment effect was sustained after the intervention was withdrawn. Total group pre-to post intervention effect show a significant decrease in pelvic angle ($p=0.005$).

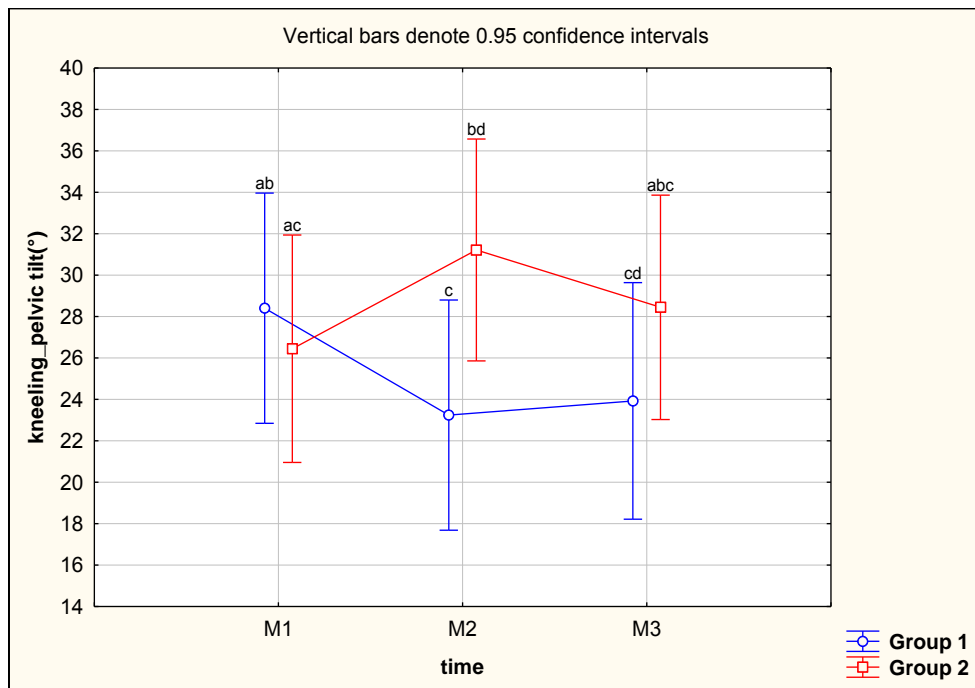


Figure 34 Effect on kneeling pelvic tilt: time*group; LS means ($p=0.001$)

Table 48 Intra-group analysis – M1-M2; M2-M3; M1-M3 for kneeling pelvic tilt (°)

	Measurement	Mean	SD	N	Diff.	SD	p
Group ₁	1_kneeling_pelvic tilt(°)	28.41	13.21				
	2_kneeling_pelvic tilt(°)	23.24	10.04	13	-5.16	6.60	0.006*
Group ₂	1_kneeling_pelvic tilt(°)	25.23	5.71				
	2_kneeling_pelvic tilt(°)	29.71	6.93	12	4.47	6.39	0.013

	Measurement	Mean	SD	N	Diff.	SD	p
Group ₁	2_kneeling_pelvic tilt(°)	22.22	9.68				
	3_kneeling_pelvic tilt(°)	22.67	10.73	11	0.45	6.57	0.722
Group ₂	2_kneeling_pelvic tilt(°)	30.34	7.96				
	3_kneeling_pelvic tilt(°)	28.14	8.72	13	-2.19	5.60	0.127

	Measurement	Mean	SD	N	Diff.	SD	p
Group ₁	1_kneeling_pelvic tilt(°)	26.57	10.92				
	3_kneeling_pelvic tilt(°)	22.67	10.73	11	-3.91	5.80	0.024*

* $p < 0.05$

6.5.3.6 Kneeling posture: shoulder-to-floor height

Values for the shoulder-to-floor height measurement were normally distributed at M1 and M2 in both groups (Table 45). The results of the repeated measures ANOVA are shown in Figure 35. There was a significant interaction between group and time ($p < .01$). The results of the post-hoc analysis as reported in Table 49 indicate there was no significant difference between the mean values of Group 1 before and after intervention and similarly between the means of Group 2 from M2 and M3, during which intervention had been applied. However a significant difference was found in Group 1 between M1 and M3 which indicate that the treatment effect continued after the intervention was withdrawn.

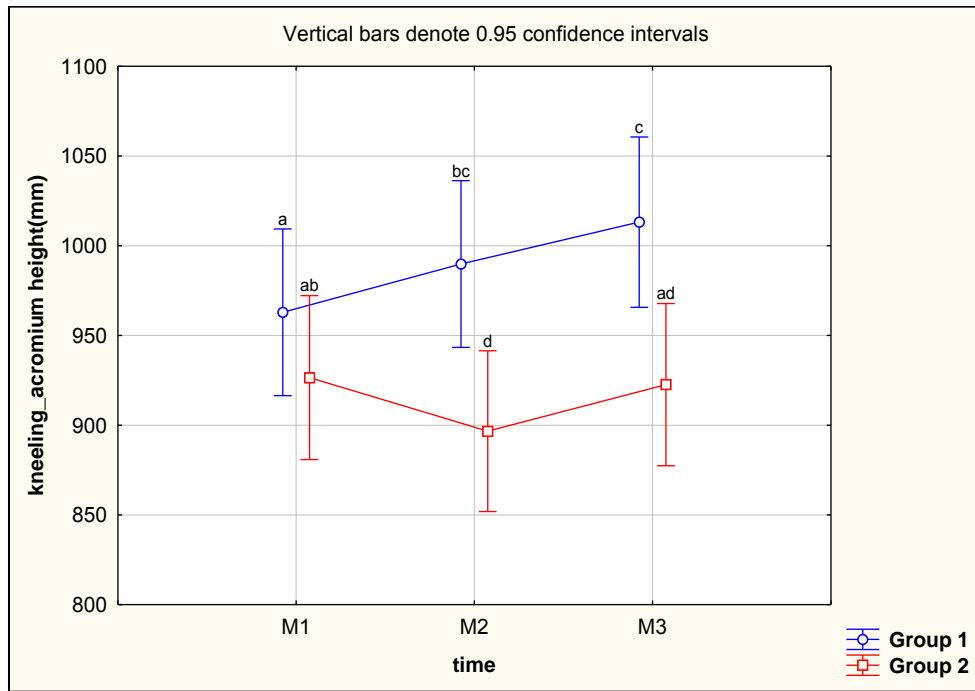


Figure 35 Effect on kneeling shoulder-to-floor-height: time*group; LS means ($p=0.006$)

Table 49 Intra-group analysis – M1-M2; M2-M3; M1-M3 for kneeling shoulder-to-floor height (mm)

Measurement		Mean	SD	N	Diff.	SD	p
Group 1	1_kneeling_acromion height(mm)	962.92	65.53				
	2_kneeling_acromion height(mm)	989.83	74.69	13	26.90	55.08	0.045*
Group 2	1_kneeling_acromion height(mm)	919.14	87.07				
	2_kneeling_acromion height(mm)	885.44	105.58	12	-33.70	53.71	0.030*

Measurement		Mean	SD	N	Diff.	SD	p
Group 1	2_kneeling_acromion height(mm)	984.15	80.38				
	3_kneeling_acromion height(mm)	1009.71	72.27	11	25.57	46.77	0.100
Group 2	2_kneeling_acromion height(mm)	904.00	102.28				
	3_kneeling_acromion height(mm)	925.67	96.74	13	21.67	40.10	0.051*

Measurement		Mean	SD	N	Diff.	SD	p
Group 1	1_kneeling_acromion height(mm)	961.03	68.42				
	3_kneeling_acromion height(mm)	1009.71	72.27	11	48.69	38.22	<0.001*

* $p<0.05$

6.5.3.7 Standing posture: a-p angle

Normal distribution for the values for standing a-p angle at M1 and M2 in both groups was found (Table 45) and the two groups did not differ significantly from one another at M1 ($p=0.07$). The results of the repeated measures ANOVA are shown in Figure 36. There was significant interaction between group and time ($p\geq.05$). Two time point analysis (total group effect) suggests that there was a significant decrease (improvement) from pre- to post intervention ($p=0.012$).

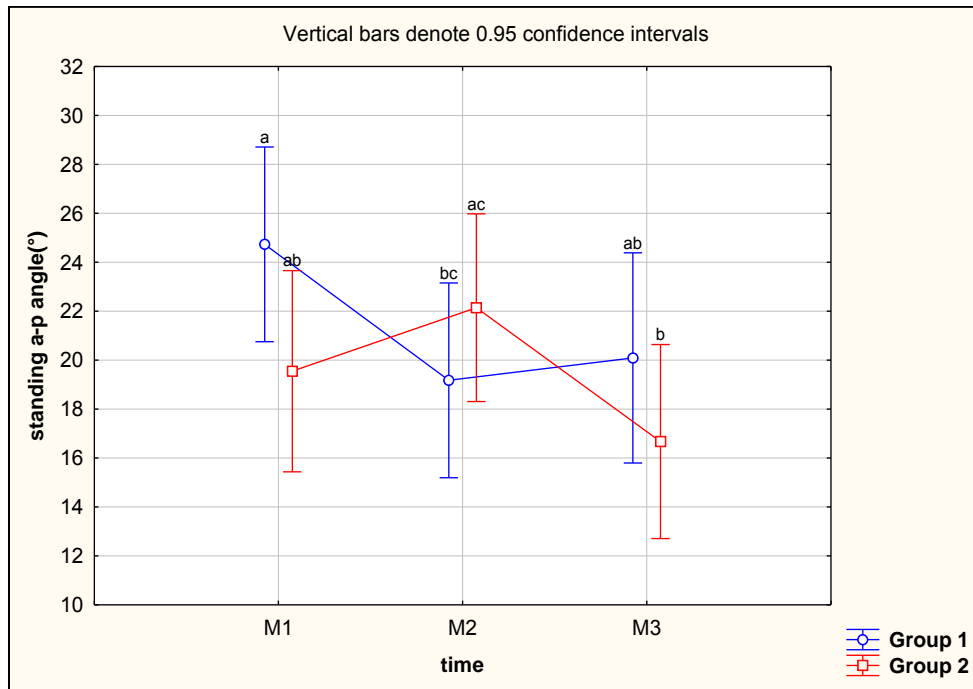


Figure 36 Effect on standing a-p angle: time*group; LS means ($p=0.054$)

6.5.3.8 Standing posture: pelvic tilt

For both groups there was normal distribution for the values for degree of a-p pelvic tilt in standing at M1 and M2 (Table 45). The two groups also did not differ significantly from one another at M1 ($p=0.73$). The results of the repeated measures ANOVA are shown in Figure 37. There was a significant interaction between group and time ($p<.05$) but the results of the post-hoc analysis indicate there was no significant difference between the mean values Group 1 before and after intervention ($p=0.051$) and similarly between the means of Group 2 from M2 and M3 ($p=0.066$) (Table 50), during which intervention had been applied. For total group i.e. two point time analysis - the difference from pre-to post intervention was however significant ($p=0.009$).

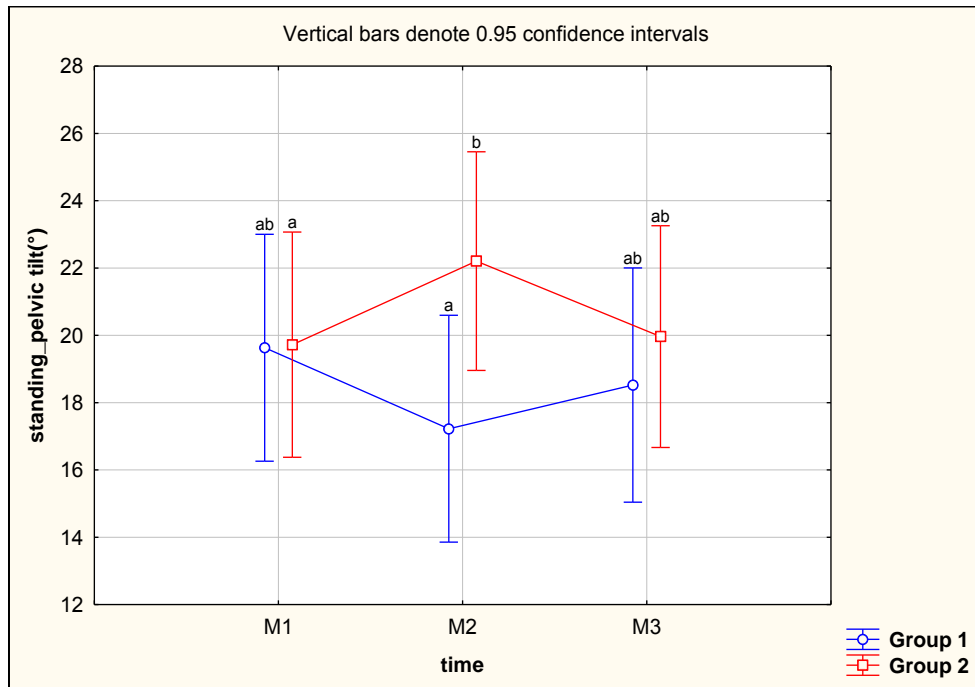


Figure 37 Effect on standing pelvic tilt: time*group; LS means ($p=0.018$)

Table 50 Intra-group analysis – M1-M2; M2-M3; M1-M3 for standing pelvic tilt (°)

Measurement		Mean	SD	N	Diff.	SD	p
Group 1	1_standing_pelvic tilt(°)	19.63	6.29				
	2_standing_pelvic tilt(°)	17.23	7.02	13	-2.41	4.25	0.051*
Group 2	1_standing_pelvic tilt(°)	18.81	5.47				
	2_standing_pelvic tilt(°)	21.10	6.51	12	2.29	5.67	0.038*

Measurement		Mean	SD	N	Diff.	SD	p
Group 1	2_standing_pelvic tilt(°)	16.26	6.83				
	3_standing_pelvic tilt(°)	17.98	4.52	11	1.72	4.42	0.316
Group 2	2_standing_pelvic tilt(°)	22.00	6.83				
	3_standing_pelvic tilt(°)	19.91	5.42	13	-2.08	3.96	0.066

Measurement		Mean	SD	N	Diff.	SD	p
Group 1	1_standing_pelvic tilt(°)	19.33	6.12				
	3_standing_pelvic tilt(°)	17.98	4.52	11	-1.35	4.09	0.390

* $p<0.05$

6.5.4 Effect of intervention on resting muscle thickness

For this section the right side only in children with diplegia and the affected side in children with hemiplegia were used in the analysis. Distribution of the values for the various resting muscle thickness measurements varied between the two groups. At M1 Group 1 showed normal distribution for the values for all measurements except for the standing resting thickness of the TrA muscle. Group 2 however did not have a normal distribution for the values relating to OE, OI and RA muscle thickness in supine as well as for resting TrA muscle thickness in standing (Table 51). Although Group 2 consistently had thinner abdominal muscles in the supine position compared to Group 1 the difference was only significant for the OE muscle at M1 ($p=0.04$) and at M2 ($p=0.05$). In standing Group 2 also recorded thinner thickness measurements for all but the TrA muscles. The difference however was significant for the RA muscle at M1 ($p=0.03$) and M2 ($p=0.04$).

Table 51 Descriptive statistics for resting abdominal muscle thickness measurements (mm) for each group at M1 and M2.

	Measurement	Group 1				Group 2			
		Mean	SD	Normality (SW)	Norm p	Mean	SD	Normality (SW)	Norm p
Supine-resting thickness (mm)	1_ TrA	2.78	0.63	0.926	0.302	2.55	0.53	0.899	0.129
	2_ TrA	3.05	0.77	0.934	0.382	2.87	0.69	0.928	0.290
	1_ OE	4.36	1.24	0.972	0.912	3.38	1.07	0.865	0.045*
	2_ OE	4.69	1.36	0.934	0.388	3.73	1.03	0.916	0.192
	1_ OI	6.67	1.37	0.956	0.696	5.99	1.76	0.856	0.034*
	2_ OI	7.25	2.17	0.844	0.024*	6.73	1.99	0.880	0.058
	1_ RA	6.51	1.03	0.929	0.335	5.71	1.02	0.838	0.020*
	2_ RA	6.76	0.83	0.949	0.588	6.29	0.90	0.852	0.024*
Standing-resting thickness (mm)	1_ TrA	2.33	0.62	0.861	0.040*	2.45	0.46	0.848	0.027*
	2_ TrA	2.79	0.91	0.851	0.029*	2.99	1.03	0.801	0.005*
	1_ OE	3.49	0.90	0.959	0.742	2.93	0.74	0.897	0.120
	2_ OE	3.65	1.20	0.950	0.593	3.35	1.01	0.905	0.135
	1_ OI	6.25	2.26	0.901	0.138	5.78	2.16	0.883	0.079
	2_ OI	6.47	1.96	0.938	0.435	6.86	2.98	0.905	0.135
	1_ RA	6.15	1.22	0.915	0.216	5.24	0.70	0.881	0.073
	2_ RA	6.31	0.94	0.955	0.677	5.55	0.85	0.886	0.072

SW = Shapiro-Wilks; * $p<0.05$

The descending order of the magnitude of relative thickness of the four abdominal muscles remained unchanged following intervention with $OI > RA > OE > TrA$. This pattern of relative thickness was seen in both the supine and standing positions.

6.5.4.1 Effect on resting TrA muscle

The results of the repeated measures ANOVA are shown in Figures 38 and 39. There was no significant interaction between group and time ($p > .05$) in either the supine (Figure 38) or standing (Figure 39) positions. Post-hoc analysis however did show a significant difference in Group 1 for standing resting TrA muscle thickness ($p = 0.035$) between M1 and M3 which suggest that treatment effect continued after the intervention was withdrawn. Also when combining the scores of the two groups, i.e. for Group 1 M1-M2 and for Group 2 M2-M3 - the two time point analysis indicate significant differences from pre- to post intervention in both the standing ($p = 0.047$) and the supine ($p = 0.020$) resting positions.

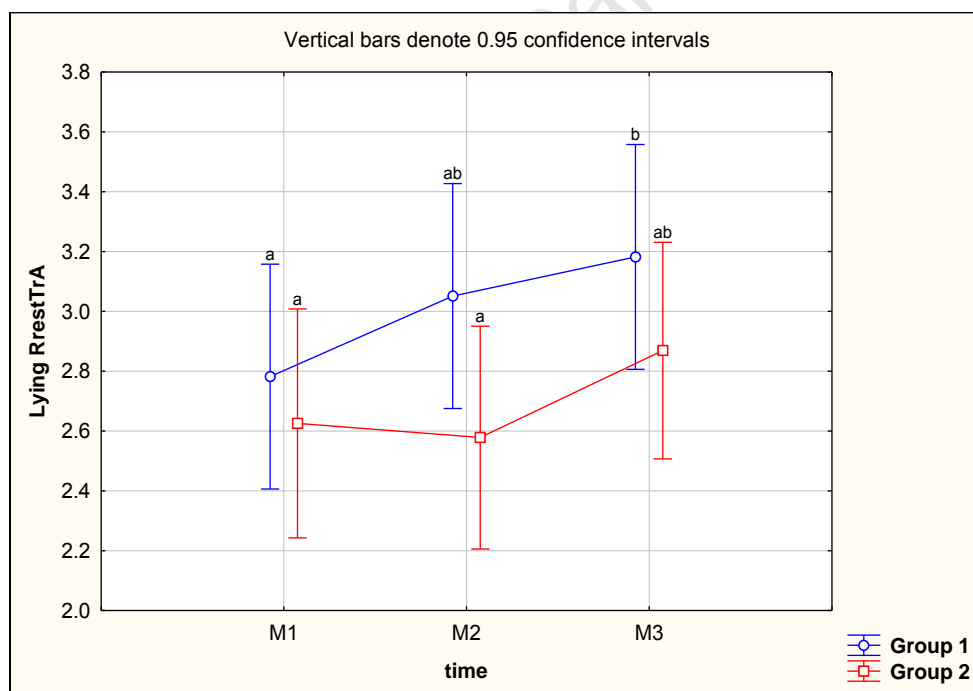


Figure 38 Effect on TrA in supine: time*group; LS means ($p = 0.494$)

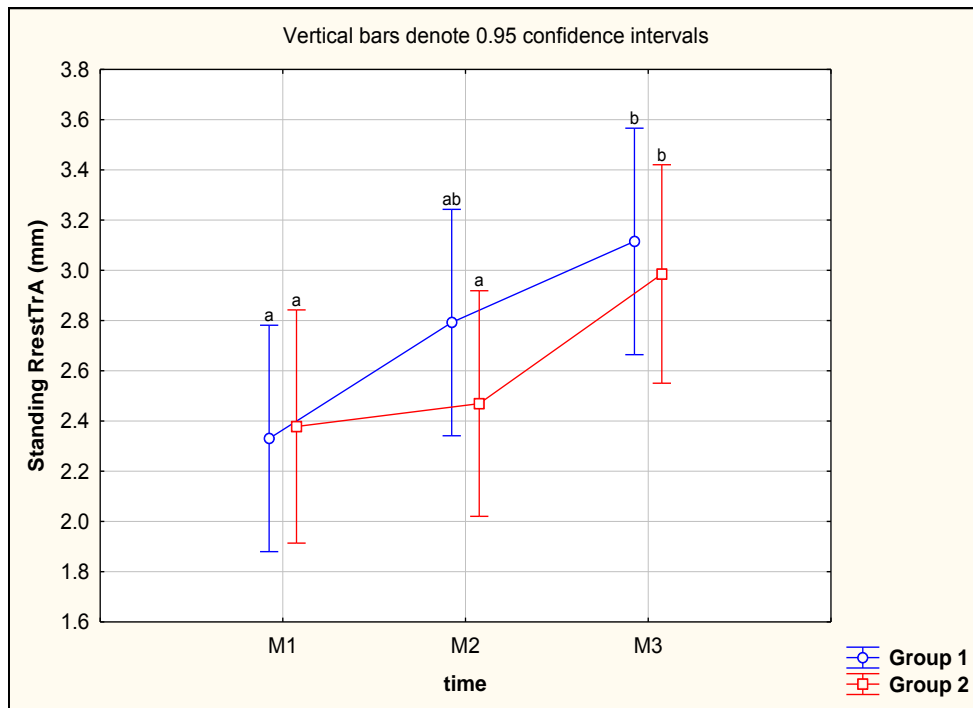


Figure 39 Effect on TrA in standing: time*group; LS means ($p=0.60$)

6.5.4.2 Effect on resting OI muscle

The results of the repeated measures ANOVA are shown in Figures 40 and 41. There was significant interaction between group and time ($p<.05$) in supine (Figure 40) while no significant interaction occurred between group and time ($p>.05$) in standing (Figure 41). For measurements in supine, the results of the post-hoc analysis indicate there was no significant difference between the mean values of Group 1 before and after intervention while for the Group 2 there was significant increase in the thickness of the OI muscle during the period in which the intervention was applied (M2 – M3). Furthermore a significant difference was found for the means in Group 1 between M1 and M3 suggesting that the treatment effect continued after the intervention was withdrawn (Table 52). Two time point analysis i.e. total group effect analysis showed significant increase in thickness for the OI in supine ($p=0.003$). No significant difference was however found in standing ($p=0.06$) between pre and post intervention measurements for the two groups combined.

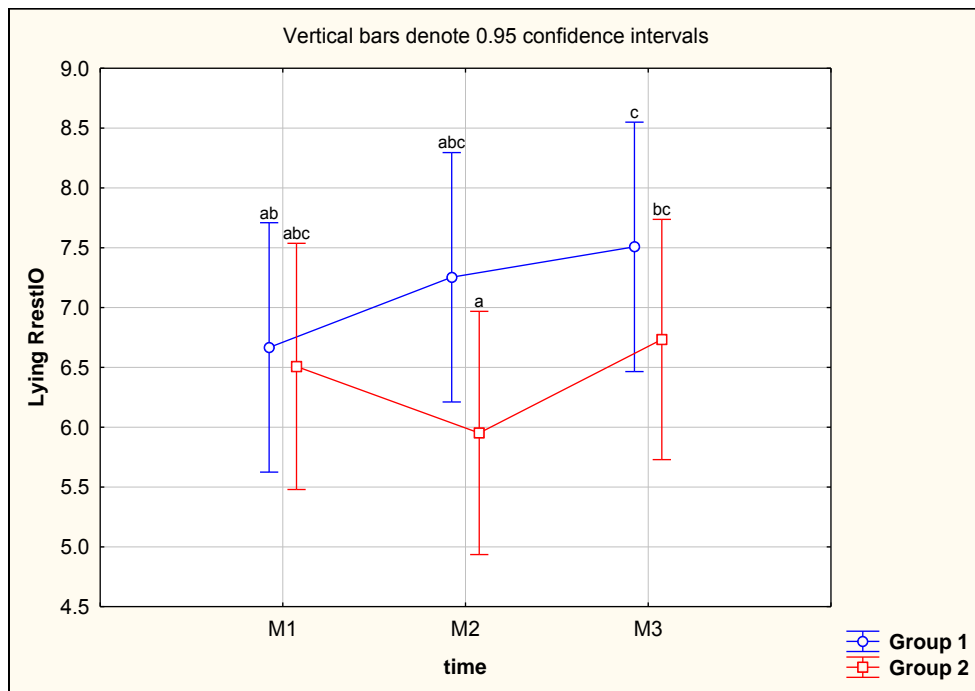


Figure 40 Effect on resting OI muscle in supine: time*group; LS means ($p=0.046$)

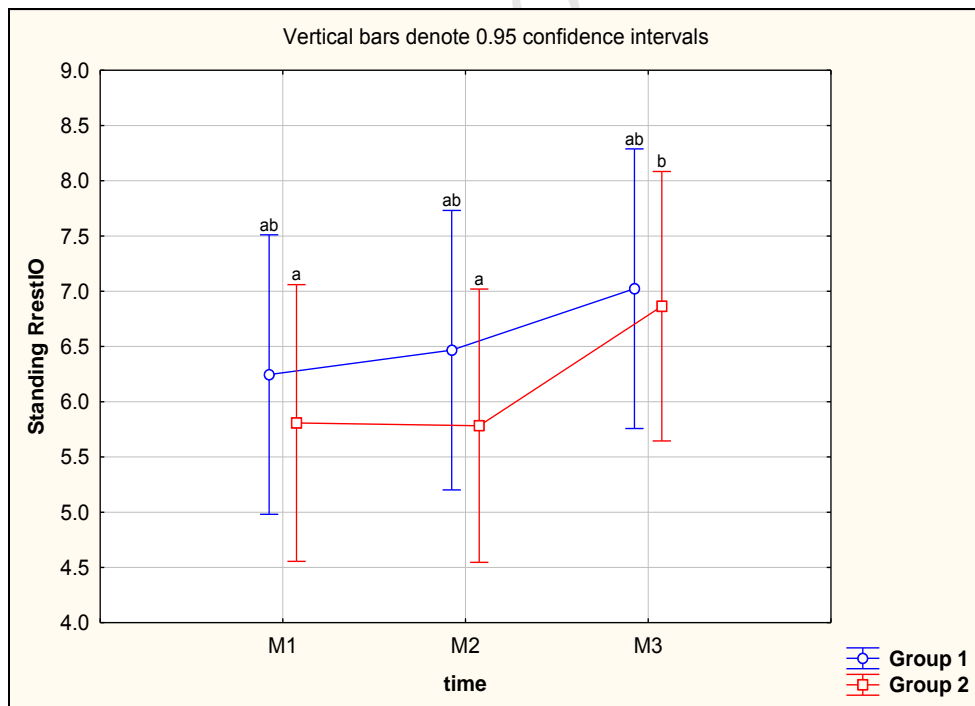


Figure 41 Effect on resting OI muscle in standing: time*group; LS means ($p=0.66$)

Table 52 Intra-group analysis – M1-M2; M2-M3; M1-M3 for resting thickness of OI in supine (mm)

Measurement - supine		Mean (mm)	SD	N	Diff.	SD	p
Group 1	1_RestOI	6.67	1.37				
	2_Rest OI	7.25	2.17	13	0.587	1.266	0.065
Group 2	1_RestOI	6.21	1.69				
	2_Rest OI	5.60	1.11	12	-0.608	1.031	0.088

Measurement - supine		Mean (mm)	SD	N	Diff.	SD	p
Group 1	2_Rest OI	7.25	2.17				
	3_Rest OI	7.51	1.85	13	0.254	1.147	0.418
Group 2	2_Rest OI	5.99	1.76				
	3_Rest OI	6.78	2.07	13	0.790	0.797	0.015*

Measurement - supine		Mean (mm)	SD	N	Diff.	SD	p
Group 1	1_Rest OI	6.67	1.37				
	3_Rest OI	7.51	1.85	13	0.841	1.282	0.009*

* $p < 0.05$

6.5.4.3 Effect on resting OE muscle

Similar results were found for OE muscle thickness measurements. The results of the repeated measures ANOVA are shown in Figures 42 and 43. There was significant interaction between group and time ($p < .05$) in supine (Figure 42) while no significant interaction occurred between group and time ($p > .05$) in standing (Figure 43). For measurements in supine, the results of the post-hoc analysis indicate there was a significant difference between the mean values of Group 1 before and after intervention as well as between the means of Group 2 from M2 and M3 during which intervention had been applied. No significant difference however was found in Group 1 between M1 and M3 which indicate that the treatment effect was not sustained after the intervention was withdrawn (Table 53). Two time point analysis (total group pre to post effect) however did show significant increase in thickness for the OE in supine ($p = 0.023$). No significant difference was however found in standing ($p = 0.057$).

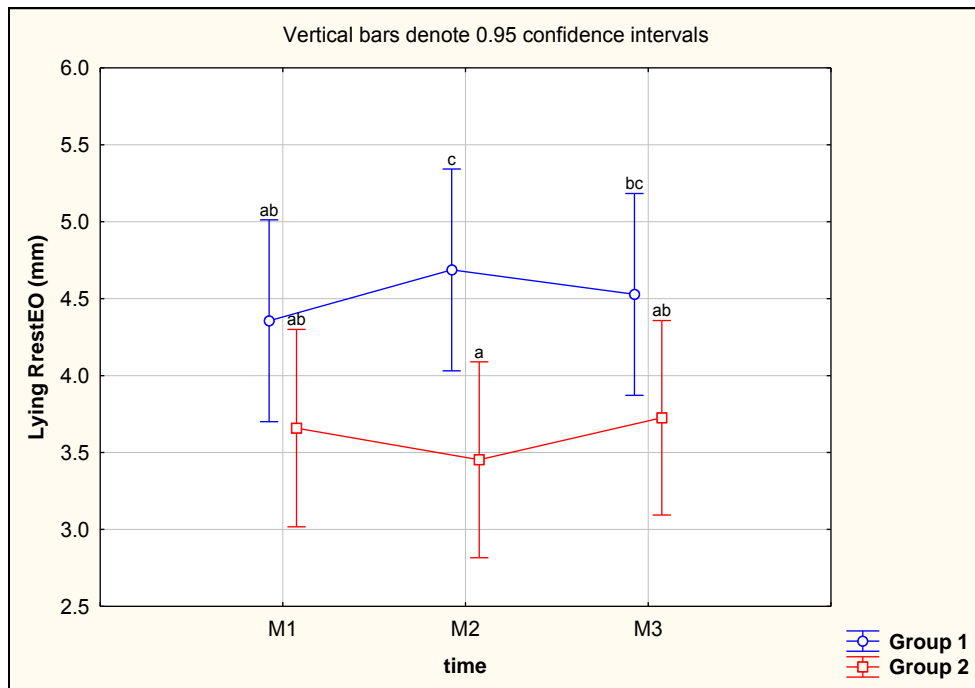


Figure 42 Effect on resting OE muscle in supine: time*group; LS means ($p=0.044$)

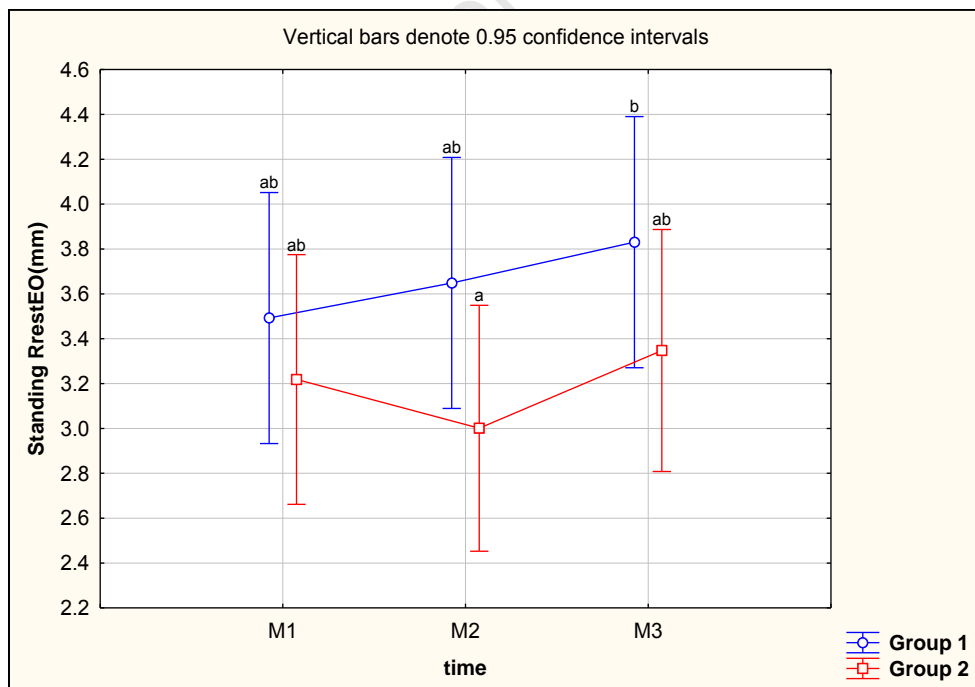


Figure 43 Effect on resting OE muscle in standing: time*group; LS means ($p=0.415$)

Table 53 Intra-group analysis – M1-M2; M2-M3; M1-M3 for resting thickness of OE in supine (mm)

Measurement		Mean (mm)	SD	N	Diff.	SD	p
Group 1	1_RrestOE	6.67	1.37				
	2_Rrest OE	7.25	2.17	13	0.587	1.266	0.038*
Group 2	1_RrestOE	6.21	1.69				
	2_Rrest OE	5.60	1.11	12	-0.608	1.031	0.202

Measurement		Mean (mm)	SD	N	Diff.	SD	p
Group 1	2_Rrest OE	7.25	2.17				
	3_Rrest OE	7.51	1.85	13	0.254	1.147	0.309
Group 2	2_Rrest OE	5.99	1.76				
	3_Rrest OE	6.78	2.07	13	0.790	0.797	0.039*

Measurement		Mean (mm)	SD	N	Diff.	SD	p
Group 1	1_Rrest OE	6.67	1.37				
	3_Rrest OE	7.51	1.85	13	0.841	1.282	0.272

* $p < 0.05$

6.5.4.4 Effect on resting RA muscle thickness

Again similar results were found for RA muscle thickness measurements. The results of the repeated measures ANOVA are shown in Figures 44 and 45. There was significant interaction between group and time ($p < .05$) in supine (Figure 44) while no significant interaction occurred between group and time ($p > .05$) in standing (Figure 45). For measurements in supine, the results of the post-hoc analysis indicate there was no significant difference between the mean values of Group 1 before and after intervention while between the means of Group 2 from M2 and M3 there was significant increase in the thickness of the RA muscle during which intervention had been applied. No significant difference was found in Group 1 between M1 and M3 (Table 54). Two time point analysis (total group pre- to post intervention) however does show significant increase in thickness for the RA in both supine ($p = 0.001$) as well as in standing ($p = 0.02$).

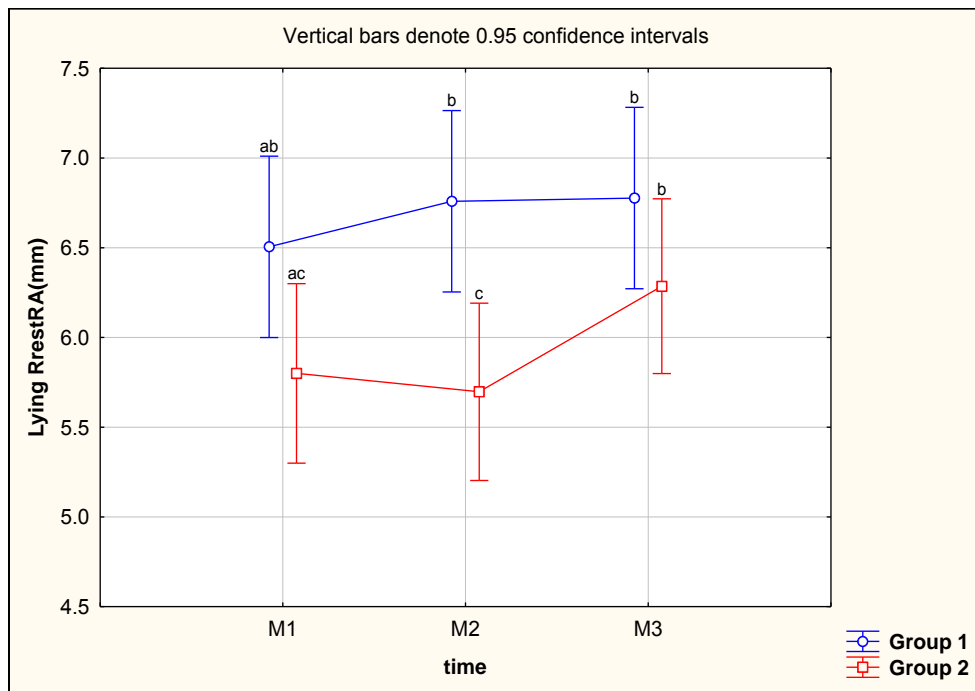


Figure 44 Effect on resting RA muscle in supine: time*group; LS means ($p=0.048$)

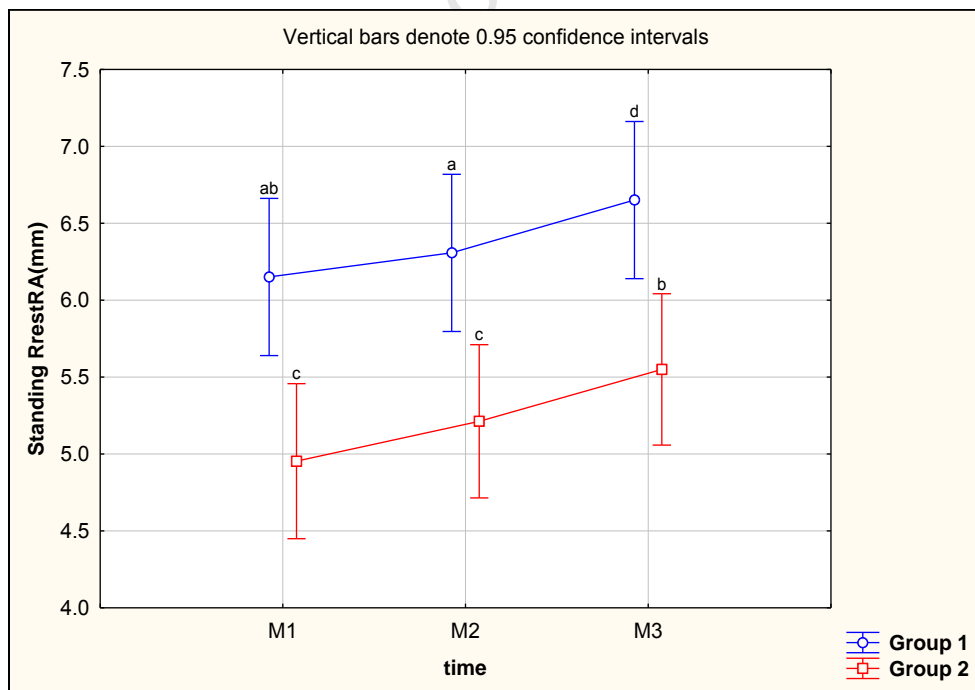


Figure 45 Effect on resting RA in standing: time*group; LS means ($p=0.870$)

Table 54 Intra-group analysis – M1-M2; M2-M3; M1-M3 for resting thickness of RA in supine (mm)

Measurement		Mean (mm)	SD	N	Diff.	SD	p
Group 1	1_Rest RA	6.51	1.03				
	2_Rest RA	6.76	0.83	13	0.254	0.583	0.120
Group 2	1_Rest RA	5.76	0.84				
	2_Rest RA	5.68	1.05	12	-0.075	0.652	0.537

Measurement		Mean (mm)	SD	N	Diff.	SD	p
Group 1	2_Rest RA	6.76	0.83				
	3_Rest RA	6.78	0.83	13	0.018	0.457	0.181
Group 2	2_Rest RA	5.71	1.02				
	3_Rest RA	6.31	0.94	13	0.592	0.588	<0.001*

Measurement		Mean (mm)	SD	N	Diff.	SD	p
Group 1	1_Rest RA	6.51	1.03				
	3_Rest RA	6.78	0.83	13	0.272	0.536	0.097

* $p < 0.05$

6.5.5 Effect on recruitment pattern (percentage change from rest to contracted state)

No significant differences were recorded for pre to post intervention measurements of percentage change from rest to contracted state in either the supine or in the standing positions (Table 55). Similarly no change in the pattern of recruitment was found.

Table 55 Effect of intervention on recruitment of the abdominal muscles (TrA, OI and RA) (% change)

	% change in the muscle		Mean (%)	SD	N	Diff. (%)	SD	t	df	p
Group 1 (M1-M2)	supine	1_TrA	4.7	19.8						
		2_TrA	7.6	26.1	12	-2.83	24.81	-0.40	11	0.700
		1_OI	5.4	20.1						
		2_OI	14.0	25.4	12	-8.52	28.67	-1.03	11	0.325
		1_RA	38.4	22.0						
		2_RA	39.3	21.1	12	-0.82	22.73	-0.12	11	0.903
	standing	1_TrA	32.2	35.0						
		2_TrA	12.7	32.5	12	19.55	37.08	1.83	11	0.095
		1_OI	14.6	16.4						
		2_OI	9.7	27.3	12	4.88	36.65	0.46	11	0.653
		1_RA	1.8	4.9						
		2_RA	-0.3	7.9	12	2.03	9.98	0.70	11	0.496
	% change in the muscle		Mean (%)	SD	N	Diff. (%)	SD	t	df	p
Group 2 (M2-M3)	supine	2_TrA	-4.2	17.6						
		3_TrA	-13.0	10.6	14	8.79	23.37	1.41	13	0.183
		2_OI	-2.6	18.3						
		3_OI	-7.5	13.8	14	4.89	21.97	0.83	13	0.420
		2_RA	34.3	25.8						
		3_RA	26.6	18.5	14	7.75	19.20	1.51	13	0.155
	standing	2_TrA	10.6	41.5						
		3_TrA	19.0	33.6	14	-8.40	36.57	-0.86	13	0.406
		2_OI	6.4	33.8						
		3_OI	4.9	20.3	14	1.54	33.67	0.17	13	0.866
		2_RA	5.2	19.4						
		3_RA	0.04	7.9	14	5.12	17.13	1.12	13	0.284

6.5.6 Effect of intervention on number of sit-ups in 1 minute

No measurements for Group 2 were recorded at M1 due to an administrative error therefore data for all children pre-intervention (M1 for Group1 and M2 for Group2) were combined. Pre to post intervention data could therefore only be analysed using a two time point framework which analyses effect of the intervention as for a single group. At pre-intervention the two groups did not differ significantly from one another for this variable ($p= 0.06$).

Results of the repeated measures ANOVA show there was a significant interaction from pre to post intervention for the groups combined ($p < 0.001$) (Figure 46). Results of the post-hoc analysis as reported in Table 56 indicate there was a significant difference between the mean values Group 1 before and after intervention and similarly between the means of Group 2 from M2 and M3, during which intervention had been applied. No significant difference was again found in Group 1 between M2 and M3 however a significant difference between M1 and M3 in this group ($p = .591$) was seen which indicate that the treatment effect was sustained after the intervention was withdrawn.

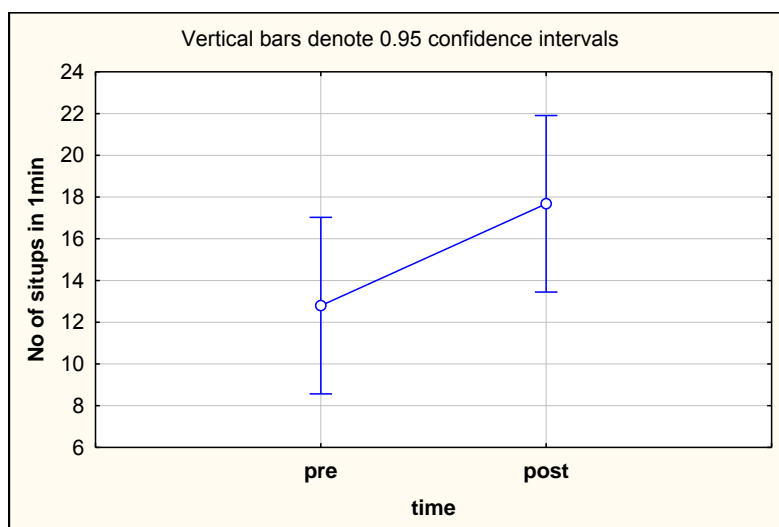


Figure 46 Effect on no. of sit-ups in 1 min for total group (Group 1 + Group 2) ($p < 0.001$)

Table 56 Intra-group analysis – M1-M2; M2-M3; M1-M3 for no of sit-ups in one minute

Measurement		Mean	SD	N	Diff.	SD	p
Group 1	1_No of sit-ups in 1min	14.31	11.64				
	2_No of sit-ups in 1min	20.92	11.38	13	6.62	6.16	<0.001*
Group 1	2_No of sit-ups in 1min	20.93	10.90				
	3_No of sit-ups in 1min	20.15	8.61	14	0.77	1.41	0.590
Group 2	2_No of sit-ups in 1min	11.29	10.90				
	3_No of sit-ups in 1min	14.43	8.61	14	3.14	4.22	0.034*

* $p < 0.05$

6.5.7 Effect of intervention on balance

The results of the repeated measures ANOVA (Figure 47) show no significant interaction between group and time ($p > 0.05$) and the results of the post-hoc analysis indicate there was no significant difference between the mean values of Group 1 before and after intervention nor between the means of Group 2 from M2 and M3, during which intervention had been applied. Total group effect using two time point analysis does however suggest the intervention to have significantly improved PBS total balance scores from pre to post intervention ($p < 0.001$).

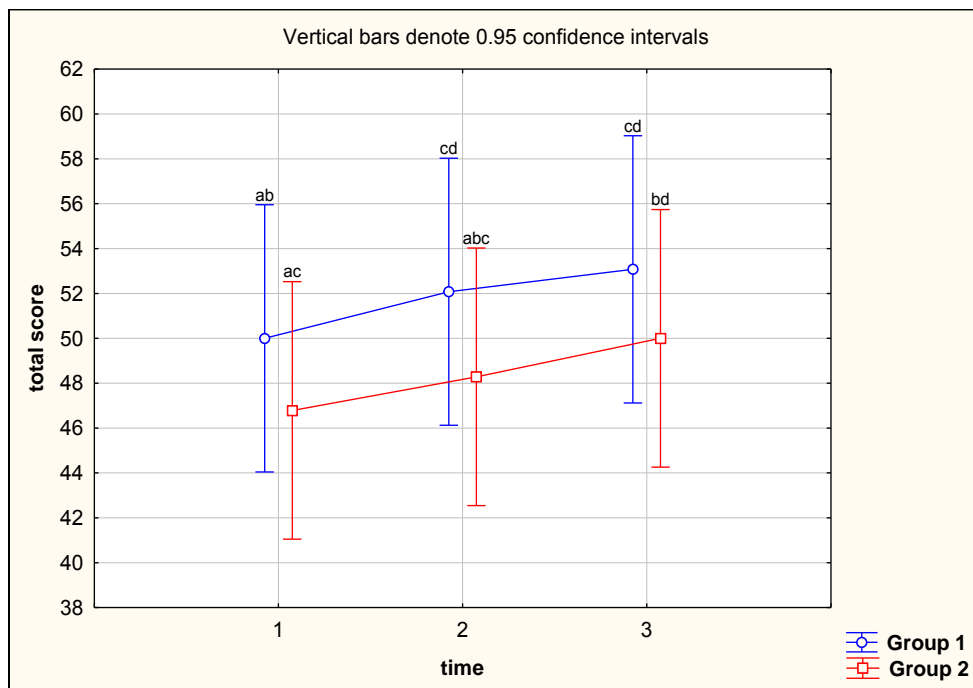


Figure 47 Effect on balance: time*group; LS means ($p=0.85$)

6.5.8 Effect of intervention on weight and BMI

The results of the repeated measures ANOVA are shown in Figure 48. There was a significant interaction between group and time ($p < .01$) and the results of the post-hoc analysis as reported in Table 57 indicate there was a significant difference between the mean values of Group 1 before and after intervention and similarly between the means of Group 2 from M2 and M3, during which intervention had been applied. No significant difference was found in Group 1 between M2 and M3 however there was a significant

difference between M1 and M3 in this group which indicate that the weight gain was sustained after the intervention was withdrawn.

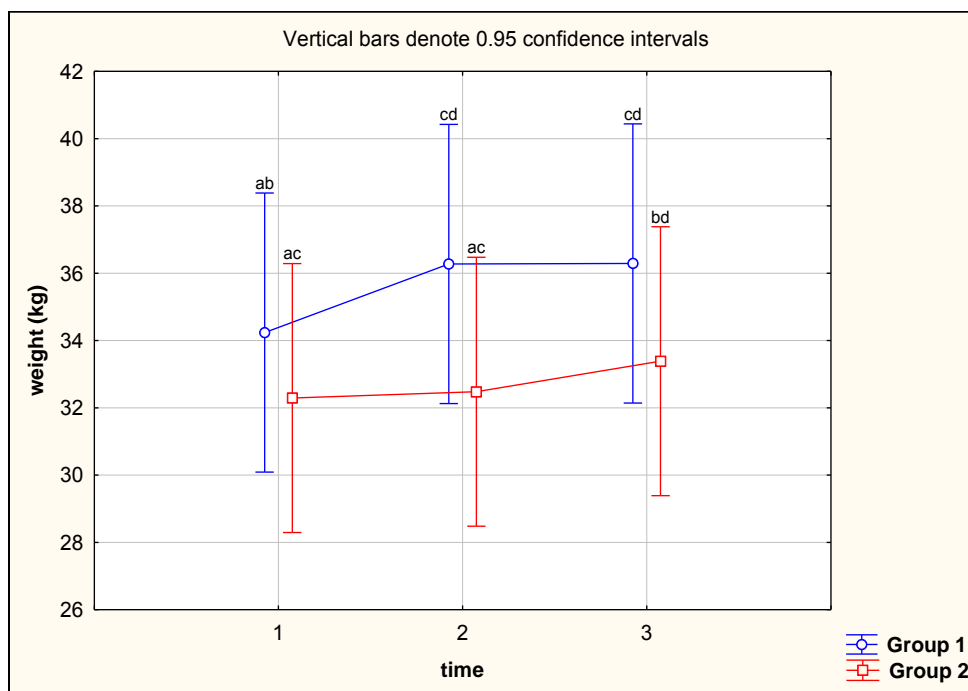


Figure 48 Effect of intervention on weight: time*group; LS means ($p=0.002$)

Table 57 Intra-group analysis – M1-M2; M2-M3; M1-M3 for weight (kg)

	Measurement	Mean	SD	N	Diff.	SD	p
Group 1	1_weight (kg)	34.24	7.58				
	2_weight (kg)	36.28	7.38	13	-2.038	2.010	<0.001*
Group 2	1_weight (kg)	32.29	7.32				
	2_weight (kg)	32.48	7.28	14	-0.186	0.532	0.591

	Measurement	Mean	SD	N	Diff.	SD	p
Group 1	2_weight (kg)	36.28	7.38				
	3_weight (kg)	36.29	7.37	13	-0.015	0.552	0.965
Group 2	2_weight (kg)	32.48	7.28				
	3_weight (kg)	33.39	7.74	14	-0.907	1.112	0.011*

	Measurement	Mean	SD	N	Diff.	SD	p
Group 1	1_weight (kg)	34.24	7.58				
	3_weight (kg)	36.29	7.37	13	-2.054	1.741	<0.001*

* $p<0.05$

Despite significant increase in thickness for selected abdominal muscles, the total increase in thickness for all four abdominal muscles (eight separate measurements) did not correlate significantly with the weight gained throughout the study period ($r=0.08$, $p=0.672$).

6.6 Summary of results

Table 58 presents a summary of the results. A 4-week trunk targeted strength training program using vibration technology/therapy had a significant impact on distance walked in one minute and upright posture in sitting as well as in kneeling. The intervention also resulted in a significant gain in resting thickness of all four abdominal muscles. There was no significant change found in recruitment activity of any of the four abdominal muscles during the head up in supine or during the leg lift in standing. The effect of the intervention on balance was not easily detectable using the PBS. While the apparent impact on posture and the ability to execute sit-ups was maintained at four weeks post intervention, the effect on all other variables (except for the resting thickness of the OE muscle) was lost.

Table 58 Summary of results

Outcome	Variable measure	Stability across 4 weeks (M1-M2 in Gr 2)	Change M1-M2 (Group 1)	Change M2-M3 (Group 2)	Total effects (Gr 1 + Gr 2)	Maintenance (M2-M3 in Gr 1)
Gait	1 min walking	stable	↑*(+11.95 m/min)	↑*(+9.71m/min)	↑* (p<0.001)	lost
Posture analysis - sitting	a-p angle	stable	↓* (-4.85°)	↓* (-5.33°)	↑* (p<0.001)	maintained
	pelvic tilt	stable	no change	no change	no change	n/a
	shoulder-to-seat height	unstable (↓)	↑* (+27.0mm)	↑* (+41.4mm)	↑* (p<0.001)	↑* (+34.3mm)
Posture analysis - kneeling	a-p angle	unstable (↑)	no change	no change	↓* (p=.034)	maintained
	pelvic tilt	unstable (↑)	↓* (-5.16°)	no change	↓* (p=.005)	maintained
	shoulder-to-floor height	unstable (↓)	↑* (+26.9mm)	↑* (+21.6mm)	↑* (p=.015)	maintained
PA - standing	a-p angle	stable	↑* (-5.58°)	↑* (-5.47°)	↓* (p=.012)	maintained
	pelvic tilt	unstable (↑)	no change	no change	↓* (p=.0009)	n/a
Balance	Total scores	stable	no change	no change	↑* (p=.001)	n/a
Ultrasound imaging of muscle thickness - in supine	TrA	stable	no change	no change	↑* (p=.047)	n/a
	OI	stable	no change	↑* (+0.79mm)	↑* (p=.003)	n/a
	OE	stable	↑* (+0.59mm)	↑* (+0.79mm)	↑* (p=.023)	maintained
	RA	stable	no change	↑* (+0.59mm)	↑* (p=.001)	n/a
Ultrasound imaging of muscle thickness - in standing	TrA	stable	no change	↑* (+0.52mm)	no change	n/a
	OI	stable	no change	↑* (+1.08mm)	no change	n/a
	OE	stable	no change	no change	no change	n/a
	RA	stable	no change	↑* (+0.34mm)	↑* (p=.020)	n/a
Sit-ups	no. in 1min	stable	↑* (+6.62)	↑* (+3.14)	↑* (p=.001)	maintained

6.7 Discussion

The results of the current study suggest that a four-week trunk targeting intervention utilising whole body vibration can significantly reduce impairment and improve function in six to thirteen year old children with STCP. Following a brief discussion on the representativeness of the current study sample and the effect of randomisation, the short and medium term effects on the ability to execute sit-ups; fast walking; upright posture in sitting, kneeling and in standing; balance; and thickness measurements recorded during rest and activity of all four abdominal muscles are discussed. The use of vibration technology to target all four abdominal muscles is also discussed. The

discussion on the use of ultrasound for investigating abdominal muscle activity is continued and recommendations for future research will conclude this section.

6.7.1 Effect of randomisation

Although the current sample size was small, data recorded for the 27 subjects ultimately recruited into the study were sufficient to detect a clinically important difference between the two groups for at least the main variable assessed i.e. gait. Where outcome did not reach significance post-hoc analysis in which the data for both groups were combined was conducted and although these results may have overestimated effect - as no comparison with a control group is being made – these results do suggest that some association between intervention and effect exists and possibly warrants further exploration.

The sample was well distributed regarding gender and classification selection (diplegia vs. hemiplegia) and all ages within the age range selected for participation in the study (six to 13 years) were represented. Representation however of the CP population was limited to only GMFCS level I-III¹⁹⁹ with 85% of participants classified as either Level I or II. The stringent BMI criteria considered for eligibility into the current study may have further limited the generalisability of the findings to that of the normal- to underweight CP population. Although a tendency towards overweight and obesity exists among children with CP³⁵⁵, the effect of increased adipose tissue was not considered in the current study. Although participants in the two groups did differ in terms of age and height, no significant differences were recorded for body mass index and these two variables were therefore not considered in the current study.

Almost 90% of children with CP present with the spastic type CP and as >70% of children present with either diplegic or hemiplegic distribution²⁷ these two types were investigated in the current study. However, whether diagnosis should be included as a 'category' or a variable, when investigating impact of intervention on function is debateable and was previously discussed in Chapter 4. With the large variation in clinical presentation within the typical CP diagnosis, functional abilities such as postural control, balance and gait may be more determined by the functioning of specific muscles and systems (more impairment level) rather than by diagnosis. The current sample size was too small for subgroup analysis, and previous findings (Chapters 3 &

4) suggested that the classification of hemiplegia vs. diplegia was not predictive of impairment or function and was therefore not further explored in this study. It is however hypothesised that classification of CP does predict impairment and function, Further investigation utilising larger sample sizes and inclusion of ataxia, athetosis, dystonic and mixed forms (not only the spastic type CP) is recommended.

In the current study there was no loss to follow-up which does strength external validity.

6.7.2 Effect of a trunk targeted intervention on impairment and function

The impact of the four week trunk targeted intervention using whole body vibration on abdominal muscle strength and the ability to execute sit-ups, gait as determined by self-selected fast walking and posture in standing, kneeling and sitting are discussed in this section.

6.7.2.1 Abdominal muscle strength

Despite ample evidence that strengthening can occur in selected musculature in children with CP^{8;40;89;375} there is very little evidence that suggests that strengthening can occur in the trunk musculature and more specifically in the abdominal muscles in these children. Although not reported, an increase in the strength of the trunk musculature is suggested following various balance^{48;225;234} and functional strengthening programs^{44;45}. The results of the current study suggest that strengthening of the abdominal muscles can occur following participation in a four week trunk targeted intervention using whole body vibration (WBV) in that a significant increase in the ability to execute sit-ups was recorded following participation in the trunk targeted intervention. Although counting the number of sit-ups executed in one minute is not a 'typical' strength measure in that it does not determine the maximal force the muscle(s) is able to generate, this measurement includes an assessment of strength, power and endurance – all components demanded from this group of muscles⁷¹.

The reported increase in thickness in the abdominal muscles post intervention suggests that at least in part that the strength changes which allowed for an increase in the number of sit-ups executed occurred at morphological level. As a significant increase in body mass was also seen in the current study, it was assumed that the increase in muscle thickness was due to an increase in muscle mass⁶⁸. The increase in

body mass however did not correlate with the total gain in thickness reported for all eight muscles. An adaptation in posture (biomechanical alignment) may also have occurred. Concurrent 3-D postural analysis in the supine and standing positions would confirm this suggestion. The apparent impact of improved abdominal muscle strength on posture and on gait (discussed below) further suggest strengthening did occur to enable these muscles to position the pelvis more favourably for improved function to occur.

6.7.2.2 Posture in standing and gait

It was hypothesised that improved biomechanical alignment and provision of a more stable base i.e. the pelvis and trunk, following a trunk targeted intervention would significantly affect gait function in children with CP. The findings of the current study support this assumption in that participants covered significantly greater distance (more than 10m/min) during self-selected fast walking while a more upright posture was observed in standing. This effect however was not maintained and at four weeks post intervention distance walked and pelvic tilt returned to baseline status - this despite participants maintaining the gains achieved in abdominal muscle strength as recorded by the number of sit-ups executed in one minute.

Core stability is a complex integration of the spine, local and global spinal musculature and neural control⁹⁷. In the current study exercises selected aimed to activate and strengthen all four abdominal muscles – both the local and global stabilisers and movers - and included both isometric and isotonic activity. Significant increase in the ability to execute sit-ups and the significant increase in resting muscle thickness in all four of these muscles suggest that strengthening did occur. Concurrent improved pelvic tilt was recorded in standing. However despite the gain in thickness the pattern of recruitment during activity of the head in supine and the leg lift in standing, of all four muscles remained unchanged. As the impact of core stability on function is dependent on the collective functioning of all the core musculature^{96;397}, limiting the strength training to the abdominal muscles only may have despite initial effect, not been strong enough to overcome other 'contributing factors' and once exposure to the strength training program ceased, this effect was lost. Similarly in the standing position the ventral abdominal muscles cannot effectively control pelvic position without counter-activity in the posterior hip musculature / extensors^{70;87;252}. Inclusion of exercises targeting the hip extensors (and hip ab- and adductors for lateral tilt control) including

exercises in the standing position may more effectively increase postural control in upright stance.

Despite inclusion of static / isometric exercises no significant change in pattern of recruitment of the local abdominal stabilisers occurred. In the supine position, where the body was fully supported the RA was primarily recruited for stabilising the trunk and although in the standing position more appropriate recruitment (as recorded by % change between resting and contracted states) of the TrA, OI and OE was seen with less recruitment of the RA, the same patterns of recruitment were seen at post intervention. It is presumed that the local stabilisers are composed of mainly Type I muscle fibres and only relatively low loads are required to increase their effectiveness^{70;100}. The exercises selected demanded a wide range of force capacity and included both static and dynamic activity and participation in the current training program did not significantly affect the ability of these muscles to contract 'more' appropriately in order to provide stability to the trunk. Inclusion of more specific isometric / static exercises across a wider range (including in the standing position) is recommended.

The regression of gait speed may also be explained by the motor learning theory. A four week exposure, although sufficient to increase strength may not have been enough to ensure true change in movement behaviour i.e. the establishment of new movement patterns secondary to experiencing the increased strength. Investigation into longer training programs is recommended.

The impact of vibration on spasticity can also not be ignored. Although exercises in the current study were executed in the supine and side lying positions (no standing exercises except for the 30-45s warm-up) and spasticity was not objectively measured, some participants anecdotally commented that their legs felt 'so loose' (sic) that it was 'easier to walk' (sic). An eight week strength training intervention using whole body vibration in adults with CP confirms that vibration can significantly decrease spasticity²⁵¹. This phenomenon may also have contributed to the increased walking speed seen in the current study. The primary aim of most non-surgical spasticity targeting interventions is to allow for easier facilitation of movement and create a window of opportunity to strengthen the appropriate muscles. As these interventions only temporarily affect tone^{246;398} it may be that a similar response is seen following vibration therapy and accounted for the decline in gait function seen at four weeks after

exercise was stopped. Although strengthening of the abdominal musculature did occur this strengthening was not enough to maintain improved biomechanical alignment at the pelvis four weeks post intervention.

6.7.2.3 Posture in sitting and kneeling

Results of the current study suggest that strengthening the trunk can affect upright posture in both sitting and in kneeling. These results however should be interpreted with caution. While it is generally acceptable for example to classify severity in children with crouch gait by measuring the degree of flexion at the knee, reference to a single variable when analysing posture is limiting and the contribution of hip and ankle angles are crucial when interpreting the underlying causes of crouch gait and or mechanisms involved^{87;265}. Three variables – forward sway, pelvic tilt and body length - were deemed appropriate to be representative of upright posture in sitting, kneeling and standing in the current study. Improvement in one or more of these variables in either position did not necessarily impact the other variable(s). In kneeling a decrease in pelvic tilt did not result in improved sway and similarly despite a decrease in forward sway as well as an increase in truncal length, strengthening the abdominal muscles did not affect the position of the pelvis in sitting. Despite demonstrated test-retest reliability these variables were not always stable over time. The control group presented with poorer measurements for some of these variables which may have exaggerated the significant difference found between the control and experimental group and suggest that these results may have been overestimated. Either these children were more tired at the time of the second measurement or validity of the measurement for investigating impact of intervention could be questioned. With 2-D photographic posture analysis there are limited measures for controlling rotation of the body or body parts which may account for the apparent lack of stability of selected variables and 3-D posture analysis is recommended.

The improvement seen in upright posture in sitting could be attributed to improved postural control / core stability. More upright posture meant less forward or backward sway which results in an increase in abdominal muscle activity as well as ventral and dorsal truncal co-contraction activity. EMG would verify this assumption. In the kneeling position despite the (inhibiting) influence of stretching quadriceps over the knee which would result in stretch of shortened hip flexors, a significant decrease in pelvic tilt was seen. In the absence of evidence that the hip extensors also gained strength as a result of the intervention, it can only be assumed that the stronger abdominal

musculature accounted for the improved pelvic position and as such contributed to the increased body length (shoulder-to-floor height measurement). Again the impact on spasticity and resultant muscle lengthening cannot be ignored.

6.7.3 Effect on balance

Balance scores were difficult to interpret following participation in the abdominal targeted exercise program and the responsiveness of this outcome measure in distinguishing impact of balance on functional activity in this population is questioned. No significant change in balance scores as determined by the Paediatric Balance Scale was found in either group from pre to post intervention, although when the scores of the two groups were combined significant improvement was seen. Although at baseline two of the four participants classified as Level III (GMFCS) scored well below (with scores of 13 and 26 out of a possible 56) participants in Levels I and II, no significant difference was noted for children between levels of functional activity. The current intervention was limited to the ventral musculature as described above and executed in either a supine or a side lying position. The training program furthermore focussed on strength gains and less emphasis was put on development of control. Synchronised co-contraction between several muscle groups is needed for good postural control and activity in standing⁴⁸. This implies that inclusion of the hip extensors and trunk extensors might have been advantageous. Inclusion of balance activities in standing on the vibrating platform could have further impacted neural drive and control of these muscles which may result in a more favourable outcome.

6.7.4 Use of ultrasound imaging for evaluating abdominal muscle activity

Although the primary aim of the study was to investigate the impact of an abdominal muscle strengthening program on impairment and function, investigation into abdominal muscle thickness measurements were also conducted to further explore the feasibility of ultrasound imaging for investigating abdominal muscle activity. Although children with STCP have thicker muscles than children with TD (Chapter 4), the reasons for this are currently merely speculative (i.e. physiologically thickened vs. abnormal biomechanical alignment). It was hypothesised that an increase in strength may result in thicker muscles. It was also hypothesised that stronger muscles could

produce better contraction as recorded by an increase in the difference between contracted and relaxed states representing greater the level of activity in those muscles. Exploring the recruitment patterns was hoped to inform strategies used by children with CP for selected activity and in the current study aimed to further explore the impact of a strength training program on these strategies.

6.7.4.1 Resting measurements

The results of the current study suggest changes occurred in the resting thickness measurements of various abdominal muscles in both the supine and standing positions. In the supine position, changes recorded were small yet significant at post intervention in all four abdominal muscles. For resting measurements recorded in standing both TrA and RA muscles showed a significant increase in thickness. Although the findings for resting thickness measurements concur with the impact the training program had on muscle strength, except for the OE muscle, these measurements were not maintained at four weeks post intervention despite the continued improved ability to execute sit-ups. Why this is so is not clear. Either counting the number of sit-ups is not a valid measurement of abdominal muscle strength or as reported above, there is no direct relationship between the thickness of any of the individual muscles and the ability to do sit-ups (Chapter 4) it is recommended that aggregated change in thickness and its contribution to the ability to execute sit-ups should be further explored.

6.7.5 Recruitment patterns

Ultrasound imaging was unable to detect significant differences in percentage change from rest to contracted state in either the supine or standing positions. This was unexpected as the previous study indicated that percentage change of the OI muscle was predictive of gait speed. Similarly no change in the pattern of recruitment occurred following the abdominal muscle strength training program despite significant improvement in posture and in self-selected fast walking speed. The large standard deviations suggest widespread variability in recruitment strategies employed for both supported (in the supine position) and un- or partially supported (in standing between parallel bars) activity which could help explain this finding. The widespread variability in recruitment patterns is not uncommon and is well documented in adults^{78;80;104;399}.

Pre-activation, efficient adaptation and synchronisation of fibre contraction - all influence motor performance. Cognitive awareness, external stimuli (including respiratory movements) and level of motivation are but a few of the factors contributing to appropriate recruitment strategies for optimal motor performance³⁷⁴. Increased awareness and repeated attempts can lead to improved recruitment strategies but without automatisation of the stability function these effects are short lived.

The four week intensive trunk targeted intervention did not focus on re-education and awareness of isolated contraction was not conducted. The emphasis of the program was on strength training as it was hypothesised that the vibration stimulus would facilitate inactive muscle fibres⁴⁰⁰. Although this seems to have occurred – significant increase in thickness was recorded for each of the abdominal muscles and the participants were able to execute more sit-ups following the intervention – minimal impact on neural control mechanisms seems to have occurred. Inclusion of more static exercises and balance activities are recommended.

US imaging may be useful for individual screening and for real time biofeedback. The success of this method is well described in the literature and is used for re-educating abdominal hollowing (a low level intensity activity) in selected abdominal muscles in order to contribute to a more stable spine^{116;322;401;402}. Effective abdominal muscle re-education / (re)habilitation using ultrasound in the paediatric population has not yet been reported in the literature.

6.8 Limitations

The following limitations were identified:

- Outcome measurements for investigating effect were selected on the basis of clinical feasibility - test re-test reliable, rapid to execute, portable and minimally intrusive. Although these measurements were able to detect change, the scope of impairment and function was limited to upright posture and self-selected fast walking speed. Impact on activities of daily living and level of participation at school and play still needs to be established.
- All children participated in the same exercise training program, following the same principles for progression and although each exercise was adapted according to individual ability, the program composition was not determined by baseline findings

regarding strength and recruitment activity. Children with a better baseline may have benefited more than children with less or even no activity without inclusion of specific exercises.

- The sample size was too small for subgroup analysis
- The sample was limited to children with spastic diplegic and hemiplegic type CP and although findings are generalisable to other spastic types of CP - study findings suggest that factors at level of impairment contribute more to functional ability than distribution of the motor impairment - the effect in children with other forms of motor impairment – dystonic, athetoid and ataxic and low tone is still unknown. Although not measured in the current study vibration can decrease tone in participants with spasticity and it is presumed that it will result in different outcome for different types of motor impairment.
- Selecting participants from the same setting may result in contamination. The measurements recorded for the control group however suggest that this did not occur and most variables measurements were stable across the four week period.
- Measurement bias – this was hopefully avoided in that the testers were blinded as to group allocation however children in their enthusiasm for this novel intervention may have divulged this information and this was difficult to control.
- No conclusive evidence informing dosage parameters for vibration using the Power Plate in this population exists and the composition of the intervention was based on current knowledge obtained from personal experience and findings reported in various adult populations. Inappropriate frequency selection, limited- and type of abdominal targeted exercises and duration of the intervention was not sufficiently explored in the current study.
- In a population where asymmetry exists activity in both the left and right sides should be investigated and collectively analysed

6.9 Recommendations

6.9.1 For clinical practice

The results of this study confirm that whole body vibration (WBV) is effective in targeting the abdominal musculature and inclusion of abdominal targeted exercise using this modality is recommended as part of any intervention program aimed at improving function. Although not yet investigated it is hypothesised that inclusion of exercise(s) targeting other identified weak muscles using vibration will significantly

improve function compared to 'dry land' exercise as there is some suggestion that facilitation of inactive muscles occur as a result of the vibration. Using ultrasound imaging for re-educating abdominal muscle activity is also recommended. It is advocated in adults although it's use in children and in a population where motor function is impaired directly as a result of a brain lesion is as yet unknown.

6.9.2 For future strengthening intervention studies

As trunk-targeting intervention using whole body vibration (WBV) was effective in children with STCP future studies could explore the following:

- the effect of vibration on spasticity
- comparison of individualised trunk targeted exercise programs with and without vibration
- inclusion of exercises demanding more specific recruitment of the deeper stabilising muscles
- the effect following inclusion of total body targeted exercise i.e. include all identified weak core musculature and not just the abdominal muscles
- include activity that demands greater neural control i.e. add exercise(s) that require balance and coordination to supplement strength gains
- the effect of various (vibration and exercise) dosage parameters
- the long term effects of WBV
- Alternative research designs such as the N=1 design. It is evident from the results of this and many other studies published in the field of rehabilitation that the variation observed among individuals makes it extremely difficult to conduct research with a high measure of external validity. When subjects have to conform to a strict set of criteria the generalisability of the findings is low⁴⁰³. Although N=1 study designs cannot demonstrate causality, these designs with multiple baseline measurements are increasingly being advocated as the best form of verification in the individualisation of treatment.

6.9.3 For ultrasound imaging for investigating abdominal muscle activity

The use of ultrasound imaging was further explored in the current study and the following is recommended when investigating abdominal muscle activity in children with CP:

- US imaging is suitable for descriptive purposes both at rest and during activity
- The instrument is also useful for description of strategies of recruitment used by children during selected activity. However for investigating impact following intervention, the measurement is not responsive enough to detect pre-activation and alternative outcome measurements such as EMG, 3-D motion analysis and MRI scanning are suggested.
- More accurate anatomical description of the abdominal musculature in children with CP is needed. This should include investigation of the direction of the fascicles, the angle of pull, the length of the muscles and impact of a-p tilt on the mechanics of the length tension relationship.

6.10 Conclusion

Targeting the abdominal muscles using whole body vibration can in the short term significantly improve posture and self-selected fast walking in six to thirteen year old children with spastic type cerebral palsy. The impact on gait and posture in the current study however was not maintained despite some evidence suggesting that the strength gained in the abdominal muscles remained. The maintained ability to execute sit-ups and the increase recorded in selected resting abdominal muscles thicknesses confirm this finding. The potential effect of exercise on spasticity while standing on a vibrating platform needs to be further investigated. The effect of the intervention on balance is inconclusive. The inclusion of exercises targeting all appropriate weak musculature involved in maintaining core stability is recommended as well as balance exercise executed in more upright positions. Regarding the use of US imaging for investigating abdominal muscle thickness the findings of the current study confirm suitability for descriptive purposes, but suggest that for investigating recruitment strategies further research is needed.

Conclusion

The undertaking of this research project was motivated by a lack of empirical description regarding the nature of the impairments with regard to trunk and lower limb control in children with spastic type cerebral palsy (STCP). Although postural- and motor control are complex, multifactorial mechanisms involving many structures and systems, this study focussed on the role of the ventral abdominal muscles in posture and gait in these children. The abdominal muscles typically contribute to stability of the trunk and upright posture and enable functional limb activity. However as no appropriate outcome measures for investigating abdominal muscle activation - particularly in children - exist, the study also explored the utility of US imaging for this purpose.

This chapter presents the main conclusions relating to the utility of ultrasound imaging for investigating abdominal muscle thickness in children with TD and in children with STCP. The results of the descriptive studies on measurements in children with TD and children with STCP are next discussed and the conclusions pertaining to the relationship between abdominal muscle activity and functioning and posture and gait are presented. Finally the conclusions regarding efficacy of a four-week trunk-targeted intervention using vibration technology are reported. Each section concludes with suggestions for practice and or further research.

7.1 Utility of Ultrasound imaging

Based on the analysis of data collated throughout this research project, the following is concluded regarding the usefulness of ultrasound imaging aimed at investigating the abdominal muscles in children:

- US imaging (by physiotherapists) is a reliable tool for measuring the resting thicknesses of all four of the abdominal muscle in children with TD and in children with STCP. There was agreement across repeated measurements of muscle thickness recorded in the supine position between testers and within tester, also with-in day and between-day measurements. Reliability is enhanced when the same tester is used for repeated measurements.
- US imaging is also reliable in children with STCP for measuring abdominal muscle thicknesses in the standing position.
- US imaging appears to be valid in that in children with TD there is divergent validity in that it can discriminate between resting and active conditions and convergent validity in that significant correlation was found between age and body stature.
- The validity for the measurement of abdominal muscle thickness during contraction is questionable. Without EMG verification it is unknown to what extent change in thickness correlates with muscle activity or how this relates to the strength of these muscles. Decreased reliability of the measurement was also observed as the resistance or load was increased.
- Measurement during contraction is currently considered reliable in both groups of children as there was agreement between repeated measures when the same tester was used. In children with TD greater variation however was seen between repeated attempts.

Recommendations for practice:

- US imaging can reliably be used by physiotherapists to describe abdominal muscle thickness during resting conditions in all children. Although normative data for resting thickness across different age groups still need to be established, comparison of absolute thickness, symmetry and relative order of thickness of the four abdominal muscles may be useful in identifying muscle imbalance.
- As resting thickness is a stable variable, repeated US measurement may be suitable for monitoring change due to growth or for investigating impact of intervention in children with TD. Normalising data (for BMI) should however be considered to ensure more accurate comparison between individuals. For repeated measures reliability can be enhanced using the same tester. In children with STCP however change in *resting* thickness of abdominal muscles may not be an

appropriate variable to measure when investigating impact of intervention as increased thickness was not found to be associated with better functioning.

- US can be used to investigate activity in the four abdominal muscles during sub-maximal contracted state in children with STCP. Although children with TD showed more variation in recruitment patterns during repeated attempts, especially when recorded by different testers, measurement by the same tester did produce reliable measurements.
- For measurements during contracted state standardisation of activity and resistance (task load) is recommended to allow for reliable comparison within and between subjects.

Recommendations for future research:

- It is currently unknown what the relationship is between activity and the change in thickness recorded during contracted state. EMG studies are recommended.
- Normative data needs to be established for both resting and contracted thickness measurements.
- The responsiveness of measurements recorded by US imaging for detecting pre-activation and the lower levels of activity required for stabilising function is not known.

7.2 Descriptive characteristics of abdominal muscle thickness and activity in children

Comparison of abdominal muscle thickness measurements in children with CP and TD showed that there are differences between these two groups in terms of:

- Children with STCP have significantly thicker muscles than children with TD.
- The OI muscle is the thickest muscle in children with STCP, while in children with TD the RA is the thickest muscle.
- Except for the OI muscles which was significantly thicker in girls with TD compared to boys, gender is not predictive of resting thickness measurements in either group
- In children with TD increasing age is associated with increasing resting thickness measurements. This was not seen in children with STCP.

- Selective recruitment occurs in both groups in that different patterns of percentage change recorded between resting and activity were recorded and is dependent on load.
- Children with CP recruit their abdominal muscles significantly less than children with TD. The thicker baseline measurements in children with STCP may have reduced the potential for contraction and thus less resultant torque is generated which may result in poorer activity performance.
- In all children recruitment of the TrA and OI muscles was significantly less than that of the RA muscle.
- The role of the OE is not clear. The EO muscle is stretched during stabilising in the supine position in both groups of children but without EMG verification it is unclear where there is activity in these muscles or not. An increase in thickness of this muscle was only recorded during unilateral limb activity or when the load increased.

In the group of children with STCP additional analysis of measurements recorded in the supine position and from measurements recorded in the standing position confirmed that:

- The muscles on the affected side are thicker than muscles on the unaffected side in children with hemiplegia.
- Position of the body affects resting thickness measures in that TrA, OE and RA were significantly thinner in standing.
- Level of activity and pattern of recruitment is also dependent on the load. When activities were performed against resistance thicker measurements were recorded in the TrA, OI and RA muscles. Similarly lifting the leg in the standing position - which is considered a more 'difficult' task than lifting the head in the supine position - the percentage change recorded in standing was significantly more than that recorded in the supine position.
- Despite children with STCP generally presenting with thicker abdominal muscles than children with TD, children with STCP who had poorer functional ability (i.e. lower GMFCS Levels) did not necessarily present with thicker muscles compared to their higher functioning peers.

Recommendations for future research:

- In children with STCP additional structural parameters such as fascicle length and angle need to be investigated. The current study suggests that the differences in percentage change recorded from resting to contracted states between the two groups of children may be attributable to morphological differences in that the abdominal musculature of children with STCP may have less potential range for shortening when compared to children with TD.

7.3 Relationships between structure and function of abdominal muscles and their relationship to motor dysfunction in children with STCP

The findings of this study concluded the following:

- Children with weaker abdominal muscle strength are more functionally impaired in that they cannot walk as fast as children who have stronger abdominal muscles.
- An increased anterior pelvic tilt is associated with a lesser ability to execute sit-ups.
- No clear relationships exist between individual abdominal muscle thickness measurements recorded in the supine and standing positions and abdominal the muscle functioning (ability to execute sit-ups); posture; and walking ability.
- The level of OI and OE muscle activity as indicated by the percentage change in muscle thickness recorded in both the supine and standing positions are predictive of the position of the pelvis in standing.
- The percentage change recorded in the OI muscle during activity recorded in both the supine and standing positions is predictive of self-selected fast walking.

Recommendations for future research:

- External validity was restricted in this research project. The four studies were limited to investigating children within the six to 13 year age band and only included children with spastic type CP. The sample was further limited in that only the diplegic and hemiplegic children were included and this was further restricted to

include only ambulant children i.e. children classified as Level I, II or III according to the GMFCS. Even within this sample considerable variation was found for US measurements during rest and contraction, as well as in abdominal muscle functioning. In a heterogeneous population such as CP, larger studies are needed to enable more appropriate sub-group comparisons.

- This research project was limited to investigating the role of the abdominal muscles to posture and lower limb function. More comprehensive assessment of all contributing factors to upright stance and gait (including that of the other trunk muscles) is needed to expand our understanding of abdominal muscle activity in function and more specifically in persons with motor dysfunction.

7.4 Can strengthening the abdominal muscles significantly improve posture and function?

A trunk-targeted strengthening exercise program for children with STCP which included both isometric and isotonic activity, executed on a vibrating platform suggested the following:

- Weak abdominal muscles can be strengthened.
- In the short term strengthening the abdominal muscles can significantly impact upright posture and increase self-selected fast walking ability. However this effect was not sustained after withdrawal from the intervention. The current study hypothesised that the short term impact of exercising on the vibrating platform on posture and functional ability may be due to (but not limited to) a reduction in hypertonia. This was inferred from anecdotal self-report of reduced stiffness in the legs as well as the unchanged resting thickness measurements despite an increase in the ability to execute sit-ups.
- The effect of increased muscle strength on balance is inconclusive.
- Standing on a vibrating platform such as the Power Plate® appears safe and effective in targeting the abdominal musculature in children with STCP. Although not significant there was an increase in activity reported for the TrA and IO muscles (stabilisers) with less recruitment of the RA muscle in standing. Using vibration appears to be effective in facilitating muscle contraction in the deeper lying abdominal muscles.

Recommendations for practice:

- Strengthening the abdominal muscles should be considered for inclusion in interventions aimed at improving function
- Careful selection of exercise demanding more appropriate muscle activity in terms of low level isometric balance control³⁹⁶ should result in more favourable functional outcome than 'traditional' facilitation techniques and progressive resisted exercise.

Recommendations for future research:

- Longer exposure to the current intervention may have a greater long term impact.
- The effect of vibration on hypertonia warrants further investigation.
- Total body targeted exercise i.e. inclusion of all identified weak core musculature and not just the abdominal muscles may have a more significant effect on functional activity and postural control .
- Inclusion of activity that demands greater neural control - i.e. add exercise(s) that require balance and coordination - may further supplement strength gains.
- The effect of various vibration and exercise dosage parameters should be explored
- Currently the long term effects of whole body vibration (WBV) are unknown.

7.5 Significance of the research

These four studies aimed to increase our knowledge regarding the anatomical structure and physiological functioning of the abdominal muscles in children with STCP in order to better inform treatment. The results suggest that US imaging is a reliable and valid outcome measure for investigating the abdominal muscles in children with STCP. Currently it is recommended that US imaging is used more for descriptive purposes and less for investigating percentage change in thickness (recruitment). It is suggested that US imaging used as a feedback tool – also known as Rehabilitative Ultrasound Imaging (RUSI)³²¹ - could also be used for training stabiliser function in children. US imaging could be used to explore additional structural parameters to help better understand why the abdominal muscles of children with STCP are thicker than those in children with STCP. Using vibration, an abdominal targeted strengthening exercise

program significantly improves posture and function in the short term, but there is a need to investigate how this effect can be maintained.

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APPENDIX 1

Intervention Approaches to children with CP

Neuro-developmental therapy (NDT)

Neuro-developmental therapy was developed by Karel and Bertha Bobath in the early 1980's²⁰⁷. NDT places emphasis mainly on interventions that normalise postural control and include reflex inhibition and facilitation techniques requiring both passive and active participation of the child. Treatment is labour intensive and is advocated one to three times per week for several months at a time. Caregivers are also taught specific handling skills and are encouraged to apply these techniques as much as possible at home.

Conductive education (CE)

Conductive education (CE) - a concept designed by Hungarian, András Pető after World War II in 1945 aims to activate the resting capacity of the brain by integrating all forms of therapy given by one individual, the conductor²⁰⁸. Therapy is based on the idea that disability can be improved through 'proper intention of actions'. The child has to initiate all activity itself instead of waiting passively for the therapist or caregiver. Movement or activity is assisted by one or more facilitator. Treatment is also intensive and time consuming.

Although the treatment varies, NDT and CE approaches have underlying similarities and try to incorporate the theories of motor learning (Carr and Shepherd, 1987) and motor control³⁴⁰. Both utilize various active and passive interventions that attempt to normalize postural control. Traditionally these approaches are based on the reflex and hierarchical models of motor control which states that the higher centres of the central nervous system (CNS) control the lower centres and therapy therefore includes reflex inhibition and facilitation of normal movement via repetition. NDT is practiced by physiotherapists, occupational- and speech therapist. NDT is individual-based and includes facilitation of normal movement patterns and feedback. These are gradually withdrawn as the movement improves⁸⁵. As a treatment approach, it is difficult to describe - it is not a single technique but rather a process of normalising tone followed by facilitation or guidance of normal functional movement patterns.

CE on the other hand is a group-based treatment approach led by a conductor. It is task specific and functional outcome is strived for regardless of the quality of movement. Both these treatment approaches are time- and labour intensive and high level evidence for efficacy of these two approaches remains inconclusive^{37;404}.

Other approaches to the treatment and rehabilitation of children with CP include:

The Vojta Concept

The Vojta Concept or reflex-locomotion uses reflexology four times per day for 20 minutes per session, to normalise posture control²⁰⁹. This method was developed by Prof. Vaclav Vojta in the Czech Republic in the early 1950's.

The Doman-Delacato-Method

The Doman-Delacato-Method²¹⁰ is controversial method developed by Glenn Doman and Carl Delacato which involves an intensive 14 hour rigid therapy regime involving parents and many volunteers and involves passive movements or patterning performed by up to five individuals in the child's home environment.

NDT is probably the most widely used form of therapy but as the development of motor control became better understood therapists approach to management and rehabilitation of these children has evolved and become more family-centered^{204;405}. This recognition of child and environmental factors in modifying the effect of outcome in CP as well as the endorsement of the International Classification of Function (ICF) by the World Health Organisation (WHO) has prompted therapists to evaluate how this wide spectrum of child and family outcomes interact with a range of intrinsic and extrinsic factors at various points in the lifespan⁴⁰⁶. Furthermore, time restraints and lack of appropriate resources, both financial and physical, has directed therapists to seek more time and cost effective intervention strategies. The health care team therefore often tends to combines the traditional approach to management of children with CP with more specific intervention techniques, which include:

Constraint-Induced Therapy

This technique is extensively used in post-stroke rehabilitation, however has also been used for the treatment of upper limb function in hemiplegic children with CP^{217;407}. One arm is constrained while the other has to perform purposeful activities. There is much variety regarding optimal program intensity and appropriate timing¹⁰. Constraining the lower limb in the CP population has also not yet been investigated. A single subject experimental study in adults in a population of stroke patients by Marklund and Klassbo (2006) showed improvement in motor function, dynamic balance and weight-bearing symmetry⁴⁰⁸. Although this therapy appears to be promising, there have been no Level I (randomised controlled trials)⁴⁰⁹ studies to date to confirm efficacy and difficulty for parents or caregivers to keep up the constraint has been raised. Concerns have also been expressed regarding the effect of constraint of the unaffected side on a growing and developing neural system⁴¹⁰. Research in this field is ongoing.

Treadmill training

With body weight support treadmill walking, children are supported by a harness while walking on a treadmill. It is based on the theory of motor learning and early task-specific training. The child practices gait with decreased load on the lower limbs, while the system provides balance and stability²⁰⁵. Following an initial study in four children aged 1.7 to 2.3 years of age⁴¹¹, further studies - also in older children - have reported improvements in the standing and walking domains of the GMFM in non-ambulant children²²¹. Hesse et al. (1995) demonstrated the use of partial weight bearing treadmill training in ambulant children to be more effective to improve walking and increase velocity as compared to physiotherapy alone²¹⁹.

While some studies have reported using the treadmill in order to determine energy expenditure while walking in children with CP^{220;275}, investigation into the effect of unsupported treadmill walking or training in ambulatory children or adults with CP is scarce. More research is needed to inform both feasibility and efficacy thereof in the CP population.

Electrical stimulation

Neuromuscular electrical stimulation (NMES) is the stimulation of a muscle through a motor nerve either via surface- or percutaneous implanted electrodes with the aim of facilitating a muscle contraction or re-educating a movement pattern, strengthening and/or increasing range of movement²⁰⁵. Two types NMES have been predominantly used in therapy in children with CP and include threshold electrical stimulation (TES) where the stimulation is applied while the child is sleeping for approximately eight hours, at low thresholds and does not elicit a muscle contraction, and functional electrical stimulation (FES) which facilitates a particular action during functional activities. FES for example with the drop-foot stimulator facilitates dorsiflexion during the swing phase of gait. Dual channel stimulators can also be used to facilitate two or more muscle groups simultaneously such as plantar flexion during push-off or terminal stance, together with dorsiflexion during swing.

Evidence for the efficacy of TES is controversial. Earlier studies reported significant changes at impairment level for range of movement and muscle strength^{412;413}. A more recent RCT investigating the effects of TES and placebo-TES on the quadriceps muscle reported no significant changes for any of the outcomes measured²²² including parental subjective perception of change. Another study investigated the effects of TES applied to the quadriceps and tibialis anterior muscles²²⁸ also reported no significant affect that could be attributed to the TES.

Findings from the literature suggest that there is more evidence for effective use of FES⁴¹⁴. Several studies reported improvements in both upper limb grasp-and-release manipulative function and lower limb gait function with FES^{229;230;415;416}. Treatment parameters however are not well reported in some of these studies, making recommendation for clinical practice difficult. Pierce et al. (2004) compared surface electrode placement (s-FES) with percutaneous electrode placement (p-FES)²²⁶ and found the method of electrode placement to differ in terms of immediate effect regarding muscle contraction strength, sensory feedback and control systems, for example ankle dorsiflexion range was greater with p-FES than s-FES and only p-FES resulted in improved ankle force production. P-FES requires surgical insertion and is therefore less available than s-FES. The evidence for effect on activity level with NMES is also not well reported, however there is increasing evidence for its efficacy in conjunction with other intervention strategies or techniques such as with

botulinum toxin injection^{417,418}, with orthotics or splints⁴¹⁵ and following selective dorsal rhizotomy⁴¹⁹.

Reactive balance training

The concept of reactive balance retraining by intensive practice in response to balance threats while standing on a movable platform has been investigated in a group of school going children⁴⁷. The study reported that such a program resulted in significant improvement in these children's ability to regain balance and when assessed on the GMFM, improvement was noted in three out of the five children for dimension D – quiet stance and anticipatory balance skills. Impact of this intervention on other functional activities was not assessed. The authors reported more efficient timing of co-contraction, shorter muscle contraction onset i.e. reacted quicker - and reduced co-contraction of the agonist/antagonist. They attributed these changes to improved proprioceptive sensitivity, enhanced synaptic activity in the sensorimotor cortex pathways or possibly due to higher level adaptations at the level of the cerebellum or association cortex.

Butler et al. (1998) investigated the effect of targeted balance training in children who had no independent sitting balance at the start of the study. A special supportive structure was designed to allow development of motor control across selected spinal joints at a time. This whole structure was positioned on an antero-posterior movable platform. The authors hypothesized that reducing information overload – accurate motor learning across a joint is dependent on correct feedback of accurate movement from all other segments and joint – would result in improved balance. All six children between two and seven years of age in the study achieved independent sitting balance in 12 to 25 weeks (mean 16 weeks). No further studies investigating this approach have however since been published and therefore feasibility and efficacy questionable.

Orthopaedic interventions

An orthopaedic surgeon, Phelps - one of the first pioneers in the field of cerebral palsy - had a more mechanical approach to the treatment of CP and aimed at correcting abnormal alignment⁴²⁰. Treatment in Phelps's mechanical approach involved performing movement patterns passively by the therapist, splinting, casting and surgery. Although not referred to as the Phelps's approach any longer, the biomechanical approach has since evolved together

with a better understanding of the mechanisms involved in motor dysfunction (refer to 2.5.11). Orthopaedic interventions targeting primary impairments associated with the brain lesion in CP include procedures to normalize or reduce hypertonicity whereas procedures targeted at minimizing the effect of secondary impairments include mainly restoration of muscle-, tendon or leg length and alignment and relocation of displaced joints.

Interventions to reduce spasticity include selective dorsal rhizotomy^{421;422} and intrathecal Baclofen pumps for large muscle groups⁴²³. Botulinum toxin injections into selected muscles⁴²⁴ offer temporary decrease in tone. Optimal timing and impact on activity and participatory level attributable to these interventions are not always well reported. Outcomes also vary considerably as do the long term effects²⁰⁵. Post-operative therapy management is also seldom reported which may have significantly impacted on outcome. All these surgical procedures are expensive, are invasive and often painful.

Alternative/other interventions

Parents of children with CP, probably due to the severe nature of the condition, sometimes seek alternative or complementary intervention(s). Interventions that have been applied or used in the CP population include therapeutic riding, acupuncture and hyperbaric oxygen. These are not traditionally physiotherapy or occupational therapy interventions and the evidence for these techniques are to date inconclusive⁴²⁵.

Therapeutic riding or hippo therapy is an intervention where the multi-dimensional movement of a horse can be used to promote posture and balance in children with CP²³⁴. More energy efficient gait²³⁵, and gross motor function as scored on the GMFM^{235;256} have also been reported following a program of therapeutic riding. Sterba et al. (2002) also reported that the parents of these children perceived changes in speech, self-esteem and emotional well-being.

Acupuncture is a traditional Chinese technique to restore the body's energy flow or Qi by inserting fine needles into specific points in the body. Treatment involves 20 minute sessions, two to five times per week for three or more weeks at a time. It has been used in children with CP to warm cold extremities²³⁸, to reduce drooling²³⁹, to improve sleep and moods and to improve bowel function²³⁷. No studies have investigated the effect of this technique on gross motor ability.

Hyperbaric oxygen is thought to “awaken” dormant brain tissue surrounding the original lesion and has also been used in children with CP. Ninety to 100% oxygen is delivered under pressure during one hour sessions, once or twice a day for ± 40 sessions. There is much debate in the literature regarding efficacy of this intervention. An uncontrolled study reported improvements in fine and gross motor function as well as an observed reduction in spasticity²³⁶. An RCT comparing low pressure O₂ delivery with hyperbaric O₂⁴²⁶ showed no difference between the two groups. This study however did show significant change in gross motor ability, cognition and memory for both groups. A high incidence of ear problems was however reported. Research in this field remains ongoing.

Assistive technology

Therapeutic intervention aims to optimize function primarily by improving internal factors. However making use of assistive devices may further enhance these goals. Any piece of equipment or system that improves postural control and function and participation in persons with CP is considered to be an assistive device²⁰⁵. Persons with CP may use one or many devices at a time and the type of device will vary throughout the lifespan. Goals for use of the devices should be clear and efficacy monitored by the health care team.

Augmentative communication devices and computers

These devices contribute significantly to communication ability in children with speech pathology and poor handwriting due to poor upper limb and manipulative function could be addressed using computers enabling children to keep up in class and learn better¹⁹⁸.

Postural support and seating systems

These include wheelchair or seat inserts aim to improve postural alignment of the head trunk and pelvis. In a study of eight children with CP a 57% increase in vital capacity and a 55% increase in expiratory time was reported when positioned in a wheelchair with lateral trunk supports and tilted as compared to seating in a normal wheelchair without an insert²⁴⁰. Evidence for anterior or posterior tilting of inserts to improve upper limb function²⁴¹ and oromotor control is however inconclusive and it is recommend that outcome is assessed individually regarding prescription thereof.

Mobility devices

Crutches and anterior- and posterior walkers can contribute to better walking ability and reduce energy expenditure while walking^{193;242}. Mobility devices also include electric and manual wheelchairs. Although these devices greatly assist in promoting independence and lessening strain on the caregiver, there is discrepancy in the literature regarding timing for introduction of these devices. Although emphasis is often on walking ability in therapy, wheelchair mobility in school and in the community, especially for longer distances may reduce or prevent secondary early degenerative changes which may result in complete loss of walking ability later in life²⁴³. On the other hand early introduction to the wheelchair in ambulatory children could also be questioned as it contributes to the high level of inactivity and disuse atrophy seen in children with CP.

Orthotics, splints and casts

These devices are used to maintain or increase joint range of movement, stabilize a joint(s), improve mechanical alignment and / or promote function. Rigid and hinged ankle foot orthoses (AFO's) may increase sit to standing ability and increase stride length and velocity^{196;244}. The effect of lower limb orthotics on energy expenditure while walking is controversial. While significant change in oxygen and ventilatory exchange when wearing orthotics compared to barefoot walking has been reported¹⁹⁴ another study found orthotics to increase energy expenditure⁴²⁷. Concern regarding the weakening effect of long term immobilization has been expressed and the use of hinged AFO's is therefore advocated²⁴⁵. There is also no evidence for the bony re-alignment capability of the ankle foot orthosis⁴²⁸. Problems experienced with orthotics in children with spasticity include poor fitting resulting in breakdown of the skin, increases the foot size and buying shoes is difficult.

Serial casting is the application of multiple casts over time with the aim of increasing range of movement. It is typically applied to the ankle and elbow, but can also be applied to the knee and wrist. Evidence for efficacy is also poor and this technique is more recently being combined with other therapeutic interventions such as Botulinum injections²⁴⁶.

APPENDIX 2

PARTICIPANT INFORMATION SHEET_US RELIABILITY STUDY

Title of the project: A study to determine the inter- and intra-rater reliability of ultrasound imaging for the measurement of the abdominal muscle thickness in typically developing children.

Reference number: 414/2006

Principal investigator: Marianne Unger, MSc Physiotherapy

Address: University of Cape Town
Faculty of Health Sciences
Department of Physiotherapy

You and your child are being invited to take part in a research project. Please read the information in this letter, and feel free to ask the study staff about anything that is unclear to you. Participation is entirely voluntary. If you do agree to participate, you are free to withdraw from the study at any time.

This study has been approved by the Ethics Committee for Human Research at the University of Cape Town, and will be conducted according to the South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

What is the study about?

This study is a preliminary trial to investigate the feasibility of ultrasound imaging for investigating activity in the abdominal muscles in children. It forms part of a larger study which aims to compare abdominal muscle activity in children with typical development to that of children with cerebral palsy in order to help therapists better understand the contribution of muscle strength or weakness in these muscles to walking function. To help us see what is going on in the muscles we want to use ultrasound imaging or scanning but as this is a new

technique which has not yet been used in children we need to do some tests to see if it is reliable. For this part of the study your child will only be assessed.

What do you need to do?

Testing will take place at the school, during school hours. Your child's height and weight will be measured. He/she will lie on his/her back on a plinth while and a resting image of the tummy muscles using an ultrasound machine will be recorded and stored for later analysis. This is followed by lifting the head onto the chest where another image is captured. Similarly a picture will be recorded while your child lifts his or her one leg. The process should take no longer than 10-15min. It is not painful, only the gel used may be a little cold initially when it is applied. You may request to be present during testing however your assistance is not essential.

Why have you been invited to take part?

Your child has been invited to take part as he/she fulfils all the criteria for inclusion into this study, i.e. he or she is between six and 13 years old and has no condition that would affect their motor functioning.

Will you benefit from taking part?

As the study does not involve any form of treatment, and your child will therefore not benefit directly, however knowledge gained from this study should enable therapists to better understand the role of the trunk muscles in children and therefore contribute to better decision-making regarding children with physical/motor problems. Neither you nor your child will be paid to take part in this study, nor will you incur any costs.

Are there any risks?

No side effects or risks have been reported for the testing procedure that your child will undergo. No allergic reactions to the gel, which serves as a contact medium for the head of the ultrasound machine have either ever been reported.

Will my child remain anonymous?

None of your child's personal details will be made public to anyone other than the study staff, and will not be published in any form. The data of your child will be stored and presented anonymously. All images and video recordings will be destroyed after completion of the study.

What happens if I have any questions?

You are welcome to address any questions to Marianne Unger on 083 556 5321 at any time. You are also welcome to contact the Committee for Human Research of the University of Cape Town ON (021) 406 6338 if you have any questions or complaints that have not been answered by the study staff.

What happens afterwards?

If you wish, you will be sent the results of the study as soon as they become available which you will be able to discuss with me.

DECLARATION OF CONSENT

I,....., hereby agree for my child.....to take part in the study entitled "A study to determine the inter- and intra-rater reliability of ultrasound imaging for the measurement of the abdominal muscle thickness in typically developing children."

I declare that:

- I have read or had read to me this information and consent form and it is written in a language I am comfortable to use.
- I have had a chance to ask any questions, and they were answered to my satisfaction.
- Participation is entirely voluntary, and I have not been pressured into taking part.

- I may withdraw my child from the study at any time without his / her future medical treatment being influenced whatsoever.
- My child may be asked to leave the study before it has finished if the study doctor or researcher feels it is in my child's best interests, or if my child does not follow the study plan as agreed to.

Signed at.....on.....

.....

Signature of parent or legal guardian

Signature of witness

DECLARATION OF INVESTIGATOR

I.....declare that:

- I explained the information in the participant letter to
- I encouraged him / her to ask questions and that I answered them appropriately and understandably.
- I am satisfied that (s)he understands the study.
- I did / did not use a translator.

Signed at.....on.....

.....

Signature of investigator

Signature of witness

DECLARATION OF ASSENT

Declaration by the child (participant) for agreeing to participate in the study.

I(*name of participant*) would like to take part in this study.

It has been explained to me what the study is about and what will be expected of me throughout the study.

I understand that I may stop taking part at any time and no one will hold it against me in any way.

.....

Signature of participant

.....

Date

University of Cape Town

APPENDIX 3

PARTICIPATION INFORMATION SHEET_INTERVENTION STUDY

Title of the projects: The effect of a 4-week trunk targeting intervention program on the position of the pelvis and lower limb function in children with spastic type cerebral palsy

Reference number: N09/08/201

Principal investigators: Marianne Unger

Address: Stellenbosch University

Faculty of Health Sciences

Department of Physiotherapy

You and your child are being invited to take part in a research project. Please read the information in this letter, and feel free to ask the study staff about anything that is unclear to you. Participation is entirely voluntary, and your child's future medical treatment will not be negatively influenced if you decide not to take part. If you do agree to participate, you are free to withdraw from the study at any time without your child's future medical treatment being influenced whatsoever.

This study has been approved by the Ethics Committee for Human Research at Stellenbosch University, and will be conducted according to the South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research. Permission from the Headmaster of your child's school as well as the Department of Education has also been obtained.

About the researcher

Marianne Unger is a registered physiotherapist with the Health Professions Council of South Africa and has previously worked as a physiotherapist at Eros school. She is now a lecturer at Stellenbosch University, where she obtained her MSc degree and is currently registered as a doctoral student at the University of Cape Town. She is doing this research as part of her PhD studies.

What is the study about?

This study aims to investigate whether an exercise program that strengthens the abdominal or tummy muscles can improve your child's posture and function. The study wants to look at your child's tummy muscles, test his balance, look at his/her posture and see how fast he can walk before and after (s)he takes part in an exercise program.

What do you need to do?

You may ask to be present during testing or attend any of the exercise sessions however your assistance is not essential. Your child will be tested and take part in the exercise program all during school hours during their therapy sessions. The tests include the following:

Your child's height and weight will be measured and the thickness of your child's tummy muscles will be measured using ultrasound, which involves placing a probe on the skin on the side of the tummy muscles while your child is lying down and also while he is standing. Some of the children at the school have already experienced this if they participated in the first part of this study which took place last year. Your child will also be asked to walk on a track around the school buildings as fast as (s)he can for 1 minute. We will also test their balance in sitting and standing. Lastly the researchers will also take some photographs from the side to record your child's posture. None of these tests will cause any pain, but should your child experience any anxiety or fear, (s)he can observe as well as have time to familiarize him/herself with the test.

(S)he will also take part in a four week exercise program which will involve tummy muscle exercises while standing on the power plate which is a large vibrating exercise platform. The aim of the vibration is to help the weaker muscles contract better.

Why has your child been invited to take part?

Your child has been invited to take part as (s)he fulfills all the criteria to be included into this study. (S)he has either diplegic or hemiplegic cerebral palsy and is between 8 and 13 years of age.

Will your child benefit from taking part?

We hope that this exercise will strengthen the tummy muscles which could improve his/her walking ability and function, especially his/her balance. Knowledge which we gain from this study will help us plan better therapy for your child and for other children with spastic type cerebral palsy in the future. Participation in the study will not cost you anything. Neither you nor your child will be paid to take part in this study.

Are there any risks?

No side effects or risks have been reported for any of the testing procedures or from participating in the exercise program that your child will undergo. Should your child however hurt himself accidentally during any of the tests the physiotherapist will attend to his/her needs and report the incident to the school nurse or doctor who will take care of your child, free of charge. And you will immediately be informed thereof by the researchers.

Will my child remain anonymous?

None of your child's personal details will be made public to anyone other than the study staff, and will not be published in any form. The data of your child will be stored and presented anonymously. The researcher *may* want to use one or two of the photographs taken of your child for publication in a professional journal or present a talk at a conference, but will ask you to sign the back of the photograph should you agree to using the photograph. Your child's face will be made unrecognizable. All other images/photos will be destroyed after completion of the study.

What happens if I have any questions?

You are welcome to address any questions to Marianne Unger on 083 556 5321 at any time. You are also welcome to contact the Committee for Human Research of the University of

Stellenbosch on (021) 938 9207 if you have any questions or complaints that have not been answered by the study staff.

What happens afterwards?

If you wish, you will be sent the results of the study as soon as they become available which you will be able to discuss with your child's physiotherapist and/or doctor. The information gained during this study may be published in a scientific journal or presented at a congress and shared with Physiotherapists at special interest meetings, without identifying any data of your child.

DECLARATION OF CONSENT

I,....., hereby agree for my child.....to take part in the study entitled "The effect of a four-week trunk targeting intervention on pelvic positioning and lower limb function in children with spastic type cerebral palsy"

I declare that:

I have read or had read to me this information and consent form and it is written in a language I am comfortable to use.

I have had a chance to ask any questions, and they were answered to my satisfaction.

Participation is entirely voluntary, and I nor my child, have not been pressured into taking part.

I may withdraw my child from the study at any time without his / her future medical treatment being influenced whatsoever.

My child may be asked to leave the study before it has finished if the study doctor or researcher feels it is in my child's best interests, or if my child does not follow the study plan as agreed to.

Signed at.....on.....

.....

Signature of parent or legal guardian

Signature of witness

DECLARATION OF INVESTIGATOR

I.....declare that:

I explained the information in the participant letter to

I encouraged him / her to ask questions and that I answered them appropriately and understandably.

I am satisfied that (s)he understands the study.

I did / did not use a translator.

Signed at.....on.....



.....

Signature of investigator

Signature of witness

APPENDIX 4

Child Assent Intervention Study

	STELLENBOSCH UNIVERSITY FACULTY OF HEALTH SCIENCES	
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PARTICIPANT INFORMATION LEAFLET AND ASSENT FORM



TITLE OF THE RESEARCH PROJECT:

The effect of a 4-week trunk targeting intervention program on the position of the pelvis and lower limb function in children with spastic type cerebral palsy Insert the title of your project.

RESEARCHERS NAME(S): Marianne Unger

ADDRESS: Stellenbosch University
Faculty of Health Science
Division of Physiotherapy

CONTACT NUMBER: 083 556 5321

What is RESEARCH?

Research is something we do to find new knowledge about the way things (and people) work. We use research projects or studies to help us find out more about disease or illness. Research also helps us to find better ways of helping, or treating children who are sick.

What is this research project all about?

This study wants to see if an exercise program that will make your tummy muscles stronger can also make you more upright and even help you walk better. You will do special tummy muscle exercises while standing on a big vibrating exercise platform. The aim of the vibration is to help the weaker muscles contract better.

We will also measure how tall you are and how much you weigh. By putting a probe on your tummy muscles – called ultrasound (the same machine your mommy had to see what you looked like before you were born!) while you are lying down and when you are standing to see how big your tummy muscles are. Some of the children at the school have already experienced this if they participated in the first part of this study which took place last year. You will also be asked to walk on a track around the school buildings as fast as you can for 1 minute. We will also test your balance. Lastly we will also take some photographs from the side to look at your posture. None of these tests will cause any pain, but if you are scared, you can just watch first and we can practice it first.

Why have I been invited to take part in this research project?

You have been invited to participate because you have spastic diplegic or hemiplegic cerebral palsy and because you go to Eros school.

Who is doing the research?

I am Marianne Unger. I am a physiotherapist, but also teach other Physio students at Stellenbosch University. I am doing this research / study to help me get my PhD degree.

Can anything bad happen to me?

Nothing bad can happen and should you hurt yourself by accident, the nurse will help you and I will phone your parents to tell them about it.

Can anything good happen to me?

Hopefully your tummy muscles will get stronger and that may help you walk better and stand and sit more upright. Your balance may also get better.

Will anyone know I am in the study?

Only myself, my research assistant – she is also a physiotherapist and my study supervisor at the university will know you are in the study. I will not use your name anywhere, so nobody will be able to know you took part. If you agree to it, I may want to use one of your photographs in an article to be published in a professional journal, but will not do so if you do not agree.



Who can I talk to about the study?

You can talk to me (083 556 5321). You can also talk to the Physiotherapists at the school (Heidi 021 6379080). You can also talk to my supervisor (Prof Jelsma 021 406 6595)

What if I do not want to do this?

You can change your mind at any time. It will not affect your therapy at all

Do you understand this research study and are you willing to take part in it?

YES

NO

Has the researcher answered all your questions?

☐

YES

☐

NO

Do you understand that you can pull out of the study at any time?

☐

YES

☐

NO

Signature of Child

Date

University of Cape Town

APPENDIX 5
Pediatric Balance Scale
FRANJOINE ET AL. (2003)²⁸⁹

Participant code: Date:

Location: Examiner:

Item Description	Score	Seconds
	0-4	(optional)
1. sitting to standing	_____	
2. standing to sitting	_____	
3. transfers	_____	
4. standing unsupported	_____	_____
5. sitting unsupported	_____	_____
6. standing with eyes closed	_____	_____
7. standing with feet together	_____	_____
8. standing with one foot in front	_____	_____
9. standing on 1 foot	_____	_____
10. turning 360°	_____	_____
11. turning to look behind	_____	
12. retrieving object from the floor	_____	
13. placing alternate foot on stool	_____	_____
14. reaching forward with outstretched arm	_____	
Total Test Score	_____	